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LEAD ISOTOPE STUDIES IN SUPERIOR AND SOUTHERN PROVINCES

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Preface

Lead isotopic investigations are carried out by the Geological Survey of Canada to obtain information on the formation of mineral deposits. Using these data, both the age of mineralization and some aspects of the genetic process leading to their formation can be determined. Integration of the information thus gained with field observations, geochemical and petrologic studies, leads to development of comprehensive metallogenic models which help explain the presence of mineral deposits in their particular geologic settings. It also enables the development and refinement of exploration and resource assessment criteria, which in turn may lead to the discovery of additional resources for Canada.

Analytical techniques developed for this study in the laboratories of the Geological Survey are, in some respects, unique. Application of the acid leach-residue method provides a new dimension for lead isotope studies that not only yields considerable additional data regarding the composition of radiogenic versus common lead isotope compositions, but may be of practical value in discriminating between sulphides associated with base-metal zones as opposed to 'barren' sulphide areas.

Model ages determined for the individual groups of deposits have a reasonably close fit to independently determined ages for all rocks. Lead isotopic model age measurements remain as the single most universally applicable way of determining the age of sulphide ores. In addition, in some deposits, important information regarding the time of metamorphism can be obtained from these data.

The sources of metal and depositional processes leading to each of the massive sulphide, gold, and iron deposit types are quite different, based on the lead isotopic data. Lead in massive sulphide deposits comes from a rather primitive, mantle-derived source in most areas, whereas lead in gold deposits is derived from a more radiogenically evolved, crustal source. Lead in sulphides associated with iron formation is commonly more radiogenic than that in massive sulphide deposits, due to addition of radiogenic lead either during metamorphism or from incorporated uranium and thorium.

W.W. Hutchison
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OTTAWA, May 1981

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LEAD ISOTOPE STUDIES IN SUPERIOR AND SOUTHERN PROVINCES

Abstract

The lead-isotope composition of 208 samples from 119 deposits and occurrences in the Superior and Southern provinces of the Canadian Shield is used to ascertain age and genetic information. The major deposit types examined in Archean rocks are volcanic hosted, massive sulphide deposits, iron formations including sulphide bodies with low base metal contents, sulphide-bearing veins, intrusion hosted Cu-Au deposits in the Chibougamau area, and both stratabound and intrusion-hosted gold deposits. Deposits examined in Aphebian rocks include Cobalt-type silver veins, intrusion-hosted veins, and disseminated and vein sulphide occurrences in sedimentary rocks. The isotopic composition of trace lead in pyrite, sphalerite, chalcopyrite and pyrrhotite, in addition to that of galena, was determined. In some non-galena samples, selective acid leaching indicated that both the leachate and residue isotopic compositions were different.

Galena samples from massive sulphide deposits have a tightly clustered isotopic composition with a model age of 2708 Ma, close to the U/Pb and Rb/Sr ages of the surrounding Abitibi-belt volcanic rocks. Distinct differences in isotopic composition of both galena and non-galena samples indicate different source-rock compositions and/or ages between the Noranda and Matagami camps. Lead in the less radiogenic non-galena samples was not derived from the same source as that in the galena samples. Galena compositions in the Stralak and Kam Kotia deposits form steep secondary isochrons, indicating a pre-2700 Ma history for the source rocks.

Lead from occurrences associated with pyritic iron formation is compositionally similar to the massive sulphide deposits. A leach-residue experiment on the Temagami Mine Road occurrence illustrates that pyrite has distinctly separate but homogeneous leach and residue compositions.

Galena from veins in Archean rocks of the Kirkland Lake area has isotopic compositions which form a secondary isochron; lead may have been remobilized into the veins from the Archean host rocks due to contact metamorphism by the Nipissing diabase sill.

Both galena and non-galena samples from the Chibougamau intrusion-hosted deposits have a wide range of isotopic compositions, indicating that lead was remobilized in one or more post-Archean stages into the veins.

Isotopic data from gold deposits forms two groups, a cluster of galena compositions with a model age of approximately 2700 Ma and a relatively radiogenic composition compared with massive sulphide deposits, and an anomalous group with data spread predominantly on two secondary isochrons ($R = 0.45$ and $R = 0.30$). Samples for the steeper isochron are mainly from syenite-associated veins in the Kirkland Lake area; these data indicate a pre-2700 Ma source rock and a post-2700 Ma emplacement time for the gold. The shallow isochron is possibly the result of redistribution of lead in Archean veins due to metamorphism by the Nipissing diabase.

Data from the Cobalt silver veins indicate a primary mineralizing event associated temporally with Nipissing diabase, and late Phanerozoic redistribution of some lead with compositions which form a secondary isochron. The New Delhi lead-zinc vein has a homogeneous isotopic composition, and may have formed contemporaneously with the Sudbury intrusion and associated breccias. The Mistassini-area veins were probably emplaced in the 2250 to 2100 Ma period; lead was derived from the Archean basement to the Mistassini Group.

In general, the data indicate that much genetic information can be gained from isotopic studies; pre-2700 Ma source rocks have an important role in the genesis of some deposits, and the metamorphic history of many areas is reflected in the differences in isotopic composition between galena and low-lead sulphide samples.

Résumé

On utilise les données sur la composition en isotopes du plomb des 208 échantillons provenant de 119 gîtes minéraux et venues découverts dans les provinces du lac Supérieur et du Sud, dans le Bouclier canadien; ces données serviront à déterminer l'âge des échantillons et à obtenir des renseignements sur leur genèse. Les principaux types de gîtes minéraux examinés dans les roches archéennes sont des dépôts de sulfures massifs et des formations ferrifères qui se sont formés dans une roche favorable de type volcanique, ainsi que des corps sulfureux à faible teneur en métaux de base, des filons contenant des sulfures, des gîtes de Cu-Au inclus dans des intrusions observées dans la région de Chibougamau, et des gîtes aurifères inclus dans les intrusions. Parmi les gîtes examinés dans des roches aphébiennes, on trouve en particulier des filons argentifères du type des minéralisations de Cobalt, des filons inclus dans des intrusions, des venues sulfureuses de type disséminé et de venues filoniennes présentes dans les roches sédimentaires. On a déterminé la

composition isotopique des traces de plomb présentes dans la pyrite, la sphalérite, la chalcopyrite et la pyrrhotine, et aussi la composition isotopique de la galène. Dans certains échantillons autres que la galène, la lixiviation sélective par l'acide a indiqué que la composition isotopique du lixiviat et celle des produits résiduels différaient.

Les échantillons de galène provenant des gîtes sulfureux massifs sont caractérisés par une composition isotopique étroitement groupée, dont l'âge caractéristique est de 2 708 Ma, c'est-à-dire à peu près l'âge obtenu par les datations U/Pb et Rb/Sr des roches volcaniques environnantes appartenant à la zone d'Abitibi. Des différences nettes de la composition isotopique des échantillons de galène et des échantillons autres que la galène indiquent une composition et un âge (ou les deux à la fois) différents de ceux de la roche mère entre les camps de Noranda et Matagami. Le plomb des échantillons sans galène, de caractère moins radiogène, ne provenait pas de la même source que le plomb contenu dans les échantillons de galène. Dans les gîtes de Stralak et de Kam Kotia, les diverses compositions de la galène forment des isochrones secondaires fortement inclinées, ce qui indique une évolution antérieure à 2 700 Ma pour les roches mères.

Le plomb rencontré dans les venues minérales associées à la formation de fer pyriteux a une composition semblable à celle du plomb provenant des gîtes sulfureux massifs. Une expérience sur les lixiviats et résidus, faite dans le cadre de l'étude des venues minérales de Temagami Mine Road, indique que dans la pyrite, la composition des résidus et des lixiviats est nettement distincte, mais homogène dans chacun de ces produits.

Dans la galène provenant de filons traversant les roches archéennes du secteur de Kirkland Lake, les compositions isotopiques forment une isochrone secondaire; le plomb a peut-être été remobilisé dans les filons à partir des roches encaissantes archéennes, en raison du métamorphisme de contact créé par le sill de diabase de Nipissing.

Les échantillons de galène et autres provenant des gîtes de Chibougamau et inclus dans des intrusions, sont caractérisés par une vaste gamme de compositions isotopiques, ce qui indique que le plomb a été remobilisé dans les filons, en une ou plusieurs étapes, après l'Archéen.

Les données isotopiques provenant des gîtes aurifères forment deux groupes – une "grappe" de composition de la galène caractérisée par un âge typique d'environ 2 700 Ma, et une composition relativement radiogène par rapport aux gîtes sulfureux massifs, et un groupe anormal dans lequel on observe un étalement général des données suivant deux isochrones secondaires (R 0,45 et R 0,30). Les échantillons correspondant à l'isochrone plus inclinée proviennent principalement de filons associés à des syénites du secteur de Kirkland Lake; ces données indiquent l'existence d'une roche mère antérieure à 2 700 Ma, et une mise en place des minéralisations aurifères datant de moins de 2 700 Ma. L'isochrone peu profonde est probablement le résultat d'une redistribution du plomb dans des filons archéens à la suite d'un métamorphisme causé par les diabases de Nipissing.

Les données relatives aux filons argentifères de Cobalt indiquent un épisode de minéralisation primaire contemporain des diabases de Nipissing, et une redistribution au Phanérozoïque supérieur d'une partie du plomb, dont les compositions forment une isochrone secondaire. Le filon plombifère et zincifère de New Delhi présente une composition isotopique homogène, et sa formation est peut-être contemporaine de celle de l'intrusion de Sudbury et des brèches associées. La mise en place du filon de la région de Mistassini date probablement de 2 250 à 2 100 Ma; le plomb est dérivé du soubassement archéen du groupe de Mistassini.

En général, les données indiquent qu'on peut obtenir une grande quantité d'information sur la genèse des minéralisations à partir des études isotopiques; les roches mères antérieures à 2 700 Ma ont joué un rôle important dans la genèse de certains gîtes, et l'histoire métamorphique de nombreuses régions se reflète dans les différences de composition isotopique entre la galène et les échantillons sulfureux pauvres en plomb.

INTRODUCTION

Lead isotope studies have become increasingly useful for obtaining both age and genetic information for a variety of mineral deposits throughout the world. One of the most appealing aspects of these studies is the possible application of the technique to metallogenic studies in districts with a variety of mineral deposit types whose relative ages and relations to host rocks are obscure. The Superior Province has produced more metal than any other geological province in the Canadian Shield, and has the largest variety of deposit types, yet systematic classification of deposits based on time and genetic relationship to host rocks is relatively undeveloped. Although stratigraphic relations have been delineated in restricted areas, as at Kirkland Lake (Ridler, 1970), Noranda (Spence and de Rosen Spence, 1975), Matagami Lake (Sharpe, 1965), and Wawa (Goodwin, 1962), the time and tectonic relationships of one greenstone belt to another have not been established. Furthermore, the histories of development of large, separated Shield areas such as the Superior and Slave provinces (which have similar K-Ar overprint ages) have not been compared. Lead isotope studies can elucidate these histories.

As part of an orientation study of the metallogeny of the southern part of Superior Province and eastern part of Southern Province, ore suites from a comprehensive variety of mineral deposit types were collected and analyzed during the period 1963 to 1966. Samples for isotopic analyses were selected in an attempt to cover the entire range of deposit types, with emphasis on the most productive types. Deposits with crosscutting dykes, or near intrusive complexes, and deposits with a range of sizes were included to test the degree of isotopic variability within a single type. Some more recent analyses with greater precision have been obtained by others on specimens from various deposits dealt with in this report, and these data confirm rather than modify the patterns and trends discussed herein.

The primary objective of this paper is to present the lead isotopic data in a form which can be used by anyone interested in deposits of the study area, for either age or genetic purposes. Some limited interpretations are attempted, with the object of illustrating the possible ways in which isotopic data can usefully be manipulated, and of drawing attention to age or genetic problems which require further work. We examine: (1) the validity of model age determinations and possible alternative histories for deposits of various types, (2) the value of determining the isotopic composition of trace-level lead in sulphides other than galena, (3) the degree to which metamorphism has affected the isotopic composition of the lead, and (4) the value of lead isotopic studies in genetic modelling.

A total of 245 analyses on 208 samples are reported. These include 15 replicate analyses of a galena standard (T1003 Broken Hill), 120 of other galena samples and 110 of other sulphides, primarily pyrite. Galena, least prone to analytical problems due to minor contaminant lead or availability of insufficient lead for analysis, yielded the most consistently reproducible results. Unfortunately galena is rare, or suspect as a possible 'late' mineral (i.e. not part of the primary suite) in many deposits. Lead isotopic studies of nickel deposits, for example, have received little attention due to the very low lead content of these deposits. In many deposits it was therefore necessary to extract and analyze lead from the 'major' sulphide mineral. Pyrite is an almost ubiquitous mineral in Superior Province deposits, and thus is a most useful medium for comparing deposits. Analysis of non-lead sulphides may be less accurate due to contamination and extraction problems, but may, on the other hand, provide information that would not be obtained by analysis of galena, even where this mineral is also present.

It has long been recognized that some galena suites contain variable mixtures of a lead with an 'ordinary' composition and radiogenic lead generated in rocks during a certain time interval and that the composition of the radiogenic component places constraints on the generative interval and thus on the time of deposition of the galena. Many suites of pyrite and other sulphides also contain lead with variable isotopic compositions. In a number of cases we have been able to distinguish isotopically distinct components of lead by selectively leaching out surficial lead, leaving behind a component that is intimately mixed with the bulk sulphide. The pyrite leachate generally contains more radiogenic lead than that in the unleached mineral and also more than that in the leached mineral residue. This discriminatory technique may be particularly useful as lead-bearing minerals almost invariably accrete at least minute amounts of radiogenic lead.

The firmest interpretations that may be made using data tabulated in this paper are those based on leads belonging to a suite that has an almost homogeneous composition and on leads belonging to a suite that can be interpreted as representing a mixture of a 'common' lead with radiogenic lead generated during some particular time interval. Plots of isotopic ratios show clusters of 'homogeneous' leads in positions corresponding to a narrow range of model ages, whereas they show mixtures as linear arrays. Slopes of these linear arrays ($^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$) may be used to derive information on the duration and timing of the period of generation of the radiogenic lead component. Lower slopes indicate longer intervals of generation, or younger starting ages and more recent times of separation of the radiogenic lead from the parent radioisotopes.

Acknowledgments

This initial work was carried out between 1960 and 1966 by S.M. Roscoe as part of a comprehensive metallogenic study of southern Superior Province. In the years 1960 to 1964 G. Archibald, P. George, and D. Fong collected samples and supplied field data. Mine and exploration geologists from virtually every company operating in Ontario and Quebec assisted with mine visits and directed us to field localities. In addition, R.J. Miller, R. Ginn, W. Gibb, and G. Hogg provided samples. Resident geologists in both Ontario and Quebec provided considerable information and field guidance; in particular, M. Latullippe (Val d'Or), J. Sharpe (Noranda), R. Savage and H. Lovell (Kirkland Lake), and R. Thompson (Cobalt) were helpful. H. Sakrison and A.K. Sinha assisted with laboratory preparation and data compilation.

J. Van Peteghem and C. Peters developed and carried out the chemical extraction procedure used to separate lead from non-galena sulphides, including the leach and residue separations. The laboratory operated under the capable supervision of R.K. Wanless.

This project was revived in 1972; Howard Poulsen and S.T. Spivak of Lakehead University did much of the plotting and preliminary computation and compilation; Poulsen assisted in establishing the data groupings and preliminary interpretation.

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THEORY

General

Lead in any mineral is a mixture of isotopes ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb. Isotopes 206, 207 and 208 are the radiogenic end products of radioactive decay of ^{238}U, ^{235}U, and ^{232}Th, respectively, and ^{204}Pb has no known parent. The abundances of the radiogenic products have increased through time. Thus ratios of $^{206}Pb/^{204}Pb$ (x), $^{207}Pb/^{204}Pb$ (y), and $^{208}Pb/^{204}Pb$ (z) are least in very old lead-bearing minerals which have been long isolated from uranium and thorium-bearing parent materials, whereas these ratios are greatest in minerals recently crystallized in systems that have scavenged and incorporated radiogenic lead generated throughout earth history.

The theoretical aspects of lead-isotope geochronology have been thoroughly treated in several papers and books, including Russell and Farquhar (1960), Kanasewich (1968), Doe (1970) and Faure (1977). These should be reviewed by the reader in order to gain a basic understanding of any lead-isotope model. Symbols used in the following discussion are explained in Table 1.

These authors all derive a set of equations similar to equations 1, 2 and 3 presented below, which describe the evolution of the isotopic composition of lead from a primeval component. In these equations it is assumed that the relative proportions of uranium, thorium and primeval lead are unchanged, except through generation of radiogenic lead by radioactive decay, between times t_0 (the starting time) and t_1 (the time of separation of the evolved lead). Lead which has evolved in a system such as this with only one stage of growth is termed a "single stage lead".

The derivations of the following equations are completely described in the aforementioned references. Using ^{206}Pb as an example:

present day $\frac{^{206}Pb}{^{204}Pb}$ = (x) = initial ratio of Pb in earth at its time of formation (a_o) + amount of lead formed during the interval t_0 to t_1 ($\mu.\{e^{\lambda t_0} - e^{\lambda t_1}\}$).

This gives rise to the following set of equations:

$$x = a_o + \mu\,(e^{\lambda t_0} - e^{\lambda t_1}) \quad (1)$$

$$y = b_o + V\,(e^{\lambda' t_0} - e^{\lambda' t_1}) \quad (2)$$

$$z = c_o + W\,(e^{\lambda'' t_0} - e^{\lambda'' t_1}) \quad (3)$$

where $V = \frac{\mu}{137.88}$

From equations 1, 2, and 3 it is evident that a 'single-stage' model may be applied to a single analysis to determine an age of final emplacement (removal from U and Th parents) of lead, using the 'geophysical' constants of age of earth, primeval lead isotope composition, and the U/Pb or Th/Pb ratio. The necessity to assume a U/Pb ratio may be avoided by using equation 4 (derived from equations 2 and 3) which is most useful in solving the age of single stage leads:

$$\frac{y - b_o}{x - a_o} = \frac{(e^{\lambda' t_0} - e^{\lambda' t_1})}{\alpha(e^{\lambda t_0} - e^{\lambda t_1})} \quad (4)$$

where $\alpha = \frac{\mu}{V} = 137.88$

Table 1. Symbols and constants used in interpretation of lead-isotopic data

Isotope ratio	at time = t_0 time of formation of the earth	at time = t (3.70 Ga) initiation of Stacey-Kramers second stage	at time = t_2 (0 Ga) present day
$^{206}Pb/^{204}Pb$	a_o	a_1	x
$^{207}Pb/^{204}Pb$	b_o	b_1	y
$^{208}Pb/^{204}Pb$	c_o	c_1	z
$^{238}U/^{204}Pb$	$\mu e^{\lambda t_0}$	$\mu e^{\lambda' t_1}$	μ
$^{235}U/^{204}Pb$	$\frac{\mu}{137.88} e^{\lambda' t_0}$	$\frac{\mu}{137.88} e^{\lambda' t_1}$	$\frac{\mu}{137.88}$ (v)
$^{232}Th/^{204}Pb$	$We^{\lambda'' t_0}$	$We^{\lambda'' t_1}$	W
Constants	**Symbol**	**Value**	**Reference**
decay of ^{238}U	λ	$0.155125 \times 10^{-9} a^{-1}$	1
decay of ^{235}U	λ'	$0.98485 \times 10^{-9} a^{-1}$	1
decay of ^{232}Th	λ''	$0.049475 \times 10^{-9} a^{-1}$	2
$^{238}U/^{235}U$ present day	α	137.88	3
Age of earth	t_0	$4.570 \times 10^9 a$	3
		$4.509 \times 10^9 a$	4
Canôn Diablo troilite lead isotopic ratios			
$^{206}Pb/^{204}Pb$	a_o = 9.307		5
$^{207}Pb/^{204}Pb$	b_o = 10.294		5
$^{208}Pb/^{204}Pb$	c_o = 29.475		5
Composition of lead at t=t_1 (3.70×10^9yr) (initiation of the Stacey-Kramers model)			
$^{206}Pb/^{204}Pb$		a_1 = 11.152	3
$^{207}Pb/^{204}Pb$		b_1 = 12.998	3
$^{208}Pb/^{204}Pb$		c_1 = 31.230	3

References: 1. Jaffey et al., 1971; 2. LeRoux and Glendenin, 1963; 3. Stacey and Kramers, 1975; 4. Cumming and Richards, 1975; 5. Tatsumoto et al., 1973.

Graphic plots of solutions of equation 4 (Fig. 1A,B) show a series of lines, called primary isochrons, for various values of t_0 that radiate from (a_o, b_o). Solution of equations 1, 2 and 3 shows that the lead evolves through time along a curved path that is unique to particular U/Pb (Fig. 1) and Th/Pb ratios; these evolutionary curves are the primary growth curves. Russell and Farquhar (1960) deal at some length with the problem of variation in μ, V, and W. These ratios may be constant for the mantle or for local areas of the earth's crust, but may vary widely, within the crust, both spatially and with time. Common leads have isotopic compositions which may have been generated by a simple, single-stage model, and their compositions usually lie near a geophysically acceptable growth curve.

Early studies (Holmes, 1946) indicated that, although lead in many deposits has a composition which lies on or near a growth curve, and is therefore common lead, some deposits have lead isotopic compositions which lie far off acceptable growth curve limits, and usually yield ages (by single stage interpretation) far in the future. Such samples are termed anomalous, and interpretation of their compositions by multi-stage models is discussed later (p. 15).

The Single Stage Model

The single stage model used by early workers is based on addition of radiogenic lead to primeval lead (a_o, b_o, c_o) of meteoritic composition, which is believed to resemble closely the primary composition of lead in the earth at time t_0 (age of the earth). The single stage model was based on measurement of lead isotopes in conformable, galena-bearing deposits, such as volcanogenic massive sulphide and shale-hosted massive sulphide deposits; the lead in these deposit types was believed by many workers to have been generated as a consequence of partial melting of a reasonably homogeneous mantle, and moved in a single event at time t_1 from the mantle to its present crustal position during a very short interval of time. This model was initially accepted as an attractive and simplified model of processes occurring primarily in the upper mantle, a model that explained the observed isotopic compositions through reasonable assumptions (see Russell and Farquhar, 1960).

More rigorous scrutiny of the model reveals that it did not account for the complex crustal and mantle processes which operate to form the lead-bearing deposits. For example, as Kanasewich (1968) pointed out, geophysical evidence indicates considerable inhomogeneity in the upper mantle, and difficulty is encountered in fitting the compositions of young (post-Mesozoic), and particularly modern, lead to primary growth curves.

From a geological standpoint, a single stage model in which all lead is derived from the mantle has little validity. Modern global tectonic analysis indicates that at least during the Phanerozoic, and probably since the Archean, much melt material, including the volcanic rocks associated with conformable massive sulphide deposits, has been generated by remelting of older crustal material such as seafloor basalt and sediment. Contamination of melted rock by exchange with and incorporation of crustal material through which the melt passes is evident (Hawkesworth et al., 1977; James et al., 1976). Thus the lead isotope composition of rocks that are produced by remelting and are genetically associated with conformable galena deposits will be a product of a variety of source materials. Finally, direct generation of 'conformable' sulphide deposits from melts by fractional crystallization is unlikely for most deposit types. The lead may have had at least a short residence time in a crustal position prior to moving to its 'final' position, during which it could have been contaminated by radiogenic lead from local sources with different U/Th ratios.

Thus geological considerations illustrate the obvious need for a modified model which accommodates meteorite (and assumed primeval earth) data and the assumption that since at least the mid-Archean lead has evolved to some degree within the crust rather than only in the mantle. The important questions to be answered are: 1) At what time in the earth's history is it necessary to depart from a simple, single stage meteoritic model, and allow for crustal recycling of lead with generation of radiogenic lead in different U/Th environments and 2) can the generation of lead in the crust be modelled on a uniform basis, such as constant crustal U/Pb and Th/Pb conditions, or is a model involving continuous change in U and Th relative to Pb with time more applicable? Cumming and Richards (1975) pointed out that ultimately the choice is between a catastrophic or a uniformitarian model.

Recent Models

Recently, three models have been proposed which incorporate many elements of the single stage evolution model, and which satisfy some of the geological considerations and yield reasonable conformity between model lead ages and independently determined wall rock ages, using the most recently determined decay constants.

(a) Cumming and Richards (1975) have tested single stage models based on simple 'best-fit' to data from deposits of all ages, and concluded that a model based on a steady linear change in U/Pb and Th/Pb with time gives an adequate fit to measured data. This model requires a continuous evolution of the earth's crust since t_0 (age of the earth) and does not allow for episodic events. Data useful for constructing isochrons and growth curves according to their model are presented in Table 2 and illustrated in Appendix Figure A.1(a).

(b) Stacey and Kramers (1975) have proposed a two stage model in which measured data are fitted to the second stage set of isochrons and growth curves. As their first stage, they use the meteoritic growth curve which is assumed to approximate the path of lead growth from time t_0 of formation of the earth to the time of initiation of some form of tectonism involving proto-crustal material. The second stage isochrons are generated from a point (t_1) on the first stage (meteoritic) growth curve. In order to fix a starting point (t_1) for the second stage, they first establish a 'best-average' value for the composition of modern lead, and assign an age of 4570 Ma (t_0) to the composition of primeval lead (meteoritic composition). The isotopic composition for the start of the second stage is determined by the intersection of the second-stage $t = 0$ isochron with the growth curve for the first stage. As the $t = 0$ isochron is fixed only at the zero Ma end of the growth curve, the slope is determined by varying the t_1 time until a best-fit is obtained to a series of isotopic compositions for deposits whose age is independently fixed. A 'best-fit' to their data is obtained with a second-stage start at $t_1 = 3700$ Ma. The isochrons and 'best-fit' growth curve for the Stacey and Kramers (1975) model are shown in Appendix Figure A.1(a). Data used in constructing the isochrons and growth curves for this model are presented in Table 2.

(c) Doe and Zartman (1979) proposed a multistage model, based primarily on the mathematical logic of Stacey and Kramers (1975). These authors proposed a multitude of 'reservoirs' in which lead is 'growing' and a series of 'orogenes' at which times lead was separated from its reservoir and incorporated in the crust.

Applicability of the Recent Models

The Stacey and Kramers (1975) model accommodates both the meteorite-based model and the assumption that lead has evolved at least partially within the crust (or at least in a

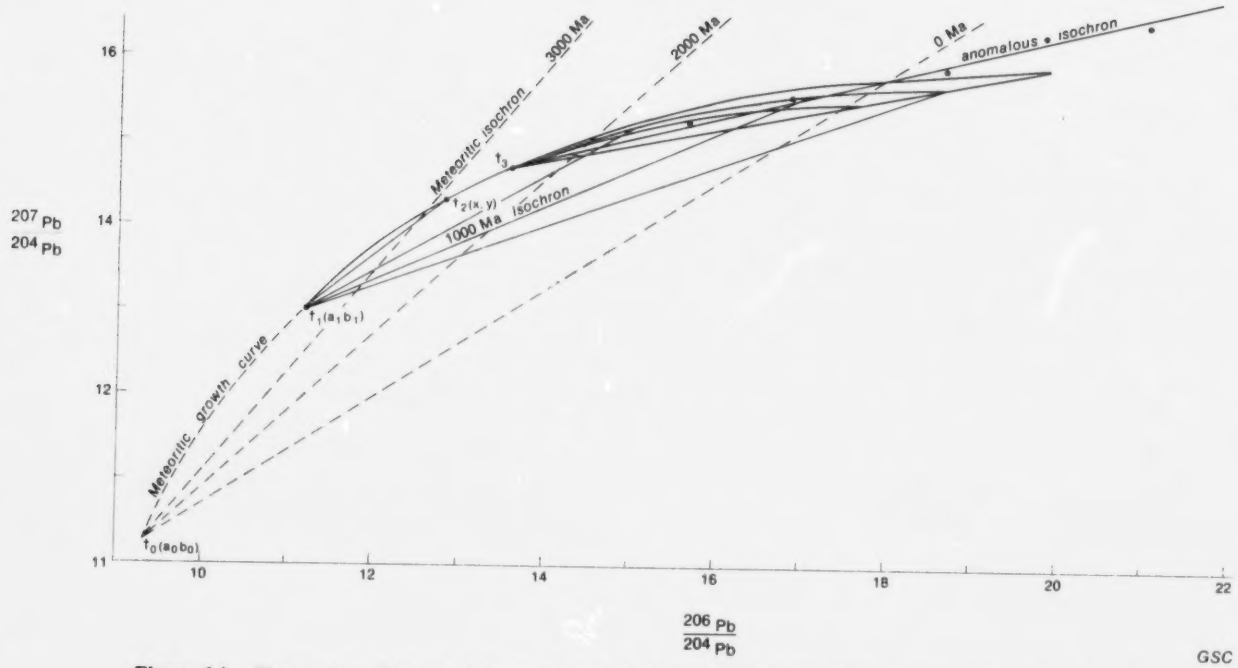

Figure 1A. *Illustration of three stage system, including a typical secondary or 'anomalous' isochron. First stage is a typical meteoritic growth curve with a few representative isochrons, starting at t_0 (4570 Ma in the Stacey-Kramers model) at composition a_0 ($^{206}Pb/^{204}Pb$)-b_0 ($^{206}Pb/^{204}Pb$). The second stage starts at t_1 (a_1, b_1) and represents the Stacey-Kramers system of isochrons and 'best fit' growth curve. The third 'stage' (t_3) is represented by a secondary isochron (heavy line with hypothetical analyses shown as dots), and a selection of growth curves.*

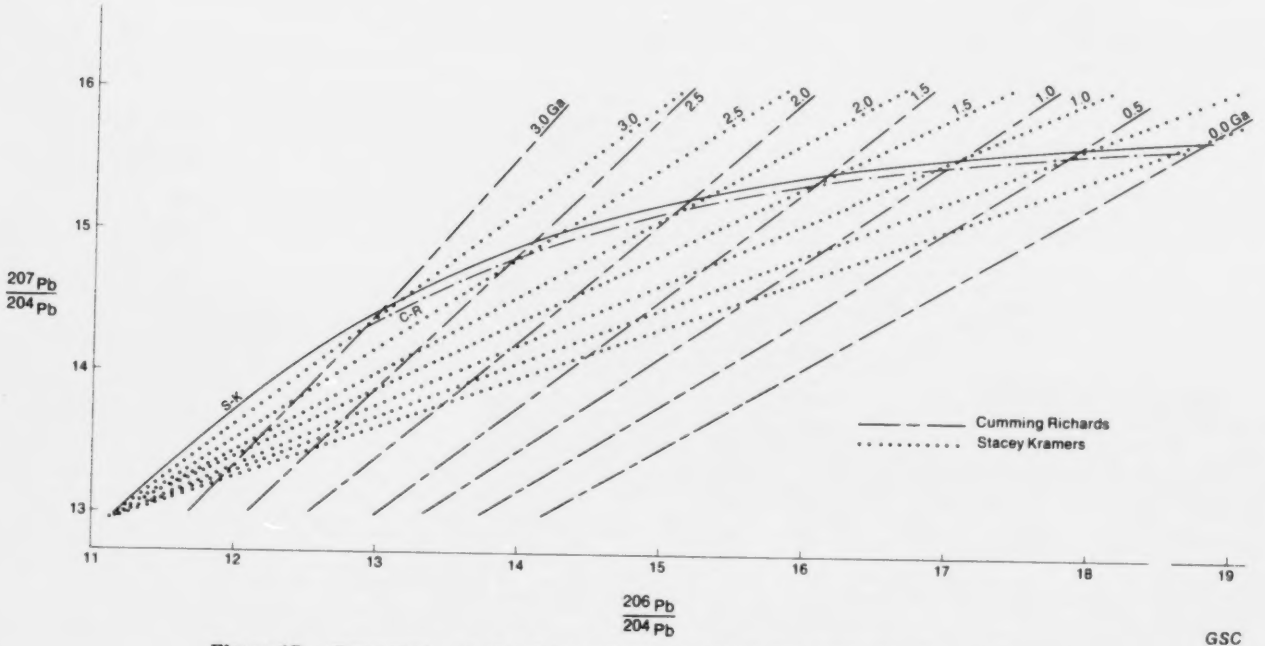

Figure 1B. *Comparison of the Stacey-Kramers (1975) and Cumming-Richards (1975) model curves and isochrons.*

Table 2. Data for construction of isochrons and growth curves for the Stacey-Kramers (1975) and Cumming-Richards (1975) models

Time	Stacey-Kramers				Cumming-Richards			
	μ = 8.0		μ = 9.74		μ = 8.0		μ = 10.0	
Ga b.p.	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$
0	17.353	15.159	18.700	15.628	16.388	14.299	18.159	15.300
0.25	17.037	15.143	18.315	15.608	16.074	14.283	17.765	15.280
0.50	16.708	15.122	17.915	15.583	15.751	14.262	17.362	15.254
0.75	16.366	15.096	17.499	15.551	15.420	14.236	16.948	15.222
1.00	16.011	15.062	17.066	15.509	15.080	14.204	16.523	15.181
1.25	15.641	15.019	16.617	15.457	14.732	14.163	16.088	15.130
1.50	15.257	14.963	16.149	15.389	14.374	14.111	15.641	15.066
1.75	14.858	14.892	15.664	15.303	14.007	14.046	15.182	14.984
2.00	14.443	14.801	15.159	15.192	13.631	13.964	14.712	14.881
2.25	14.012	14.685	14.634	15.051	13.246	13.860	14.231	14.752
2.50	13.564	14.537	14.088	14.80	12.851	13.729	13.737	14.588
2.75	13.098	14.347	13.520	14.639	12.446	13.564	13.231	14.381
3.00	12.613	14.104	12.931	14.343	12.301	13.356	12.712	14.121
3.25	12.109	13.793	12.317	13.965	11.606	13.093	12.181	13.793
3.50	11.586	13.395	11.680	13.481	11.171	12.793	11.637	13.380
3.70	11.152	12.998	11.152	12.998				

high U/Pb environment) since some specific time in the early Archean. Evidence from Greenland (Black et al., 1971), Labrador (Hurst et al., 1975) and the Minnesota River Valley (Goldich and Hedge, 1974) indicate that supracrustal rocks formed as early as 3700 Ma ago. Thus the beginning of the second-stage of Stacey and Kramers' model might conform to the time at which crustal processes, involving recycling of heterogeneous crustal material, started. For purposes of this paper, 'single stage' model ages will be calculated by the Stacey and Kramers model, using the parameters outlined in Table 1.

The choice of a model is dictated by best experimental fit to independently measured ages of deposits. The model proposed by Doe and Zartman (1979) is perhaps theoretically the most successful, in that it allows for adjustments based on tectonic setting. Unfortunately the Precambrian areas dealt with in this report cannot be readily assigned to a particular tectonic model. Consequently a more general lead isotopic evolutionary system must be used.

A more complete assessment of the models, based on published data as well as the data contained in this report, is presented in the summary section (p. 89) of this report.

Anomalous Lead Compositions

The isotopic composition of lead in some deposits is clearly discordant with the accepted age for the host rocks. A family of "anomalous" leads may have excess radiogenic lead and usually is recognized by discordance relative to a commonly accepted growth curve. Samples with anomalous compositions usually form a linear relationship on graphs of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$, if the samples are from a single genetic family. These linear relationships are actually 'secondary isochrons' and result from the addition of variable amounts of radiogenic lead, to some single stage lead, or less likely, from the mixing of two "single stage" leads. The slope (R) of the secondary isochron may be interpreted by equation 5, as follows:

$$\frac{\Delta^{207}Pb/^{204}Pb}{\Delta^{206}Pb/^{204}Pb} = \frac{(e^{\lambda' t_r} - e^{\lambda' t_s})}{137.88(e^{\lambda t_r} - e^{\lambda t_s})} \qquad (5)$$

This is a special case of equation 4, with "t_r" and "t_s" replacing "t_0" and "t_1". The time "t_r" represents a time when radiogenic lead began to accumulate. The time "t_s" represents a subsequent time when the radiogenic lead was separated from parental uranium and thorium, and mixed in varied proportions with an earlier formed common lead to give a series of isotopic compositions which form a secondary isochron of slope (R) on the aforementioned plots.

If a family of leads defines a secondary isochron with slope R, various possible values for times t_s are fixed by times assigned to t_r and vice versa. Moreover, as pointed out by Russell and Farquhar (1960), for any given R the possible ranges of t_r and t_s are constrained by the fact that t_s cannot be less than zero or greater than t_r. The maximum possible date for t_r ($t_r$max)* is obtained when t_s is zero (i.e. present day), resulting in the following equation which is identical to that used to obtain a $^{207}Pb:^{206}Pb$ date on lead extracted from a radioactive mineral:

$$R = \frac{e^{\lambda' t_r} - 1}{137.88(e^{\lambda t_r} - 1)} \qquad (6)$$

The minimum possible date for t_r ($t_r$min)* corresponds to the maximum possible date for t_s ($t_s$max) which occurs or is obtained when the generative period t_r-t_s is considered to be vanishingly short, that is when t_s is effectively the same as t_r. Russell and Farquhar termed this limiting condition t_i or t instantaneous – the time of instantaneous generation of lead with a given isotopic ratio R – and they developed the following equation:

$$R = \frac{\lambda'}{\alpha\lambda} + \frac{e^{\lambda' t_i}}{e^{\lambda t_i}} \qquad (7)$$

* Kanasewich (1968, p. 212) used the term t_{max} for the time limit termed $t_r$max in this paper, and t_{min} where we use $t_r$min or the equivalent $t_s$max or t_i. The more specific terms are used in this paper to avoid ambiguities concerning the beginning and end of a lead generative period, on the one hand, and the time of deposition of the lead-bearing deposit, on the other.

The time t_S may correspond to the time of formation of a mineral deposit containing varied amounts of radiogenic lead whose generative period began at time t_r or alternatively, depending on the deposit type and its history, it may correspond to a time when minor amounts of radiogenic lead were introduced into a pre-existing lead-bearing deposit. The time t_r, again depending upon individual situations, may represent the age of ultimate source rocks of the lead, the age of adjacent rocks, or the age of the deposit. The limits on t_S and t_r imposed by the above equations are as follows: $O < t_S < t_i$ and $t_i < t_r < t_r max$. In many cases these limits are far broader than age constraints that can be deduced with certainty from geological relationships. We can generally obtain more limited possible age ranges by applying geological constraints to t_S or t_r.

The dependent relationship between t_r and t_S for any given R provides a powerful tool for testing concepts concerning the history of deposits containing anomalous lead. We generally have some information about one or more of the following: (i) the geological age of the deposit(s) with relationship to associated rocks, (ii) the approximate ages of host rocks and younger rocks as indicated by local or regional geochronological studies, (iii) the oldest possible rocks that might have contributed lead to the deposit(s), and (iv) isotopic dates related to metamorphic phenomena likely to have caused separation of radiogenic lead from radioactive minerals. If we assign to t_S various values corresponding to the younger of these phenomena, and to t_r values corresponding to earlier events, we may find pairings of the two that best fit one or another hypothesis concerning the origin of the deposit. Alternatively, we may find evidence of a lead-forming event or a radiomineral-forming event that is not reflected, or not reflected accurately, by other geochronological data or interpretations therefrom. Many examples of such tests are given in this paper.

According to Kanasewich (1968) binary lead mixtures may also be formed by mixing of two ordinary leads so that the slope of the resulting line of isotopic ratios might not define R and t_r-t_S constraints as outlined above. This possibility is geologically unlikely, and not considered routinely when analyzing our data. However, analysis of the leach-residue data from one example (discussed later), the Temagami Mine Road occurrence, indicates that it may be possible to combine two homogeneous components to give an apparent secondary isochron. Furthermore, it is expected that binary mixtures, for example of two common leads, would become contaminated with local unrelated radiogenic lead during the mixing process, leading to diffuse patterns rather than the observed precise alignments on the isotopic plots.

ANALYTICAL PROCEDURES

Chemical Extraction Procedures

Most of the Geological Survey of Canada lead isotopic analyses reported in this paper were performed in 1963. Since that was the first time this laboratory had undertaken the extraction of relatively small amounts of lead from sulphides other than galena, some development work was required. Techniques and methods used in this study by the geochronology section of the Geological Survey were also adopted by Isotopes Incorporated in their analyses of the samples listed in this report.

Preparation of galena samples for mass spectrometric analyses was very simple; a sample of approximately one milligram of galena was crushed in a clean agate mortar, suspended in a drop of water and placed on a pre-baked rhenium filament. Excess water was evaporated using a heat lamp, and a drop of boric acid was added and taken to dryness under the heat lamp. In later work on the same project, the galena was dissolved in nitric acid and reprecipitated using H_2S gas. This step gave the advantage of some purification of the PbS and a smaller, more uniform grain size of the material to be mounted on the filament.

The procedure used for the extraction of lead from sulphides other than galenas was more complex. A series of isotopic analyses on lead extracted from the Temagami Mine Road pyrite (61 RF 0388) did not yield reproducible results (see unleached (U) analyses Appendix; Table A.2, Deposit C1). An insight into this problem was provided by Wampler (in Kulp, 1963) who demonstrated in a study of lead in sedimentary pyrites, that two types of lead co-exist in the pyrites. One type is surficial and can be removed by leaching with dilute hydrochloric acid. The other type is tightly bound and can only be extracted by dissolution of the pyrite.

Following this precedent, leach-residue lead extractions were performed on pyrite 61 RF 0388. Two samples of lead with distinctly different isotopic compositions resulted from these extractions, the more radiogenic lead being dissolved by the leach solution and the less radiogenic component being

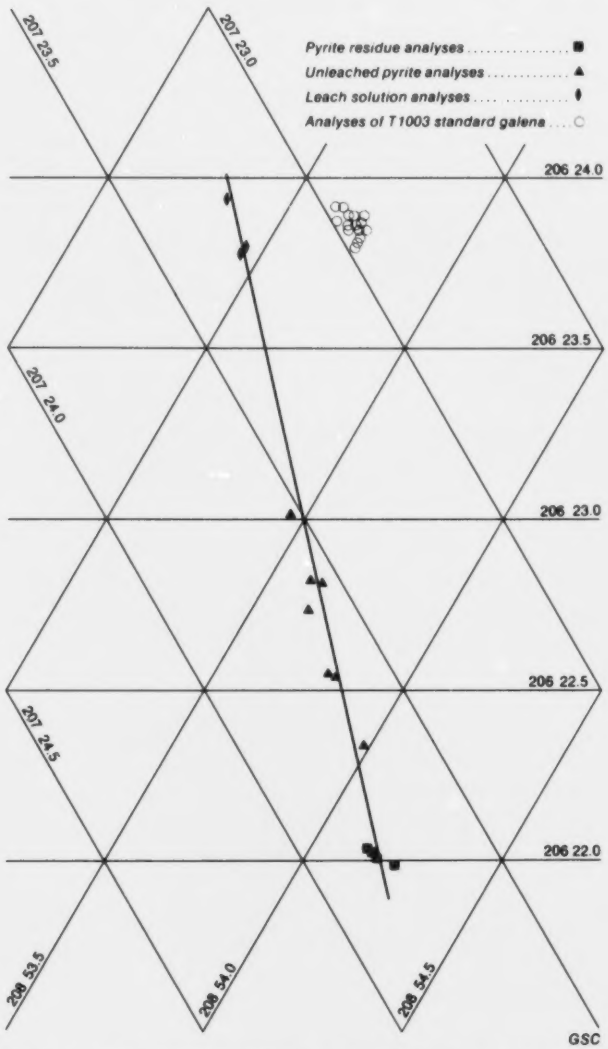

Figure 2. *Data from leaching experiments on a pyrite sample (61 RF 388). For comparison, the replicate analysis of T1003, the standard galena, are also shown.*

associated with the residual pyrite (leached, L, and residue, R, analyses respectively, Appendix; Table A.2, Deposit C1). Analyses of the unleached pyrite did not give reproducible results because the lead in this pyrite was a variable mixture of these two phases.

These results pointed out the desirability of analyzing both the leach and residue phases in all sulphides other than galena. This procedure was followed when feasible, but in some cases analyses were also made on lead from the unleached samples. Such cases resulted when the lead level in the leach or residue phase was too low to permit isotopic analysis or when the amount of sample available was very small. For reasons of economy, some analyses contracted to Isotopes Incorporated were only attempted in the unleached mode.

Experiments were performed to determine the concentration of acid and duration of leach which would yield the optimum separation of the two phases of lead in the Temagami Mine Road pyrite, 61 RF 0388. As a preliminary step portions of the pyrite were leached with hot hydrochloric acid, varying in normality from 0.25N to 6.00N. Qualitative detection of iron in the resultant leach solution was used as an indication that the leaching process had not only dissolved the surficial lead, but had attacked the pyrite itself, releasing lead from the residual phase into the leach solution. Appreciable iron was detected in solutions with concentrations of 4N and greater providing an upper limit to the concentration of acid used in further experiments. Pyrite and other sulphides were then subjected to three different leach treatments: two hours in hot 3 N HCl, four hours in hot 3 N HCl, and twenty hours in hot 1.5 N HCl. Lead was extracted from each leach solution and pyrite residue and analyzed isotopically.

The results are those given in Appendix Table A.2 and plotted on trilinear graph paper in Figure 2. Results on the standard galena sample T-1003 are also plotted for purposes of comparison. The results both of the leach analyses on 61 RF 0388 and those of the residue analyses define groups comparable in size to the group of standard galena results indicating the equivalence of the three leach treatments. In a similar experiment on a different pyrite, it was shown that two hour leaches in hot 0.25 and 0.50 N HCl were insufficient to remove all the leachable lead. Thus, in order to conserve time during chemical processing, the two hour leach in hot 3 N HCl was adopted as the standard leaching procedure. Although developed for pyrite samples, the procedure was also applied to other (non-galena) sulphides analyzed during the course of this project.

After leaching, the residual pyrite was separated from the leach solution by filtration, washed, and dissolved in a mixture of concentrated nitric and hydrochloric acids. Both the leach and residue solutions were taken to dryness at this stage and redissolved in 8 N HCl. Lead was extracted from both solutions by a dithizone extraction procedure following extraction of excess iron by isopropyl ether. Lead sulphide was precipitated using H_2S gas and mounted on the mass spectrometer filament with a drop of boric acid as described above.

The results of the leach and residue analyses indicate that each lead phase is essentially homogeneous in isotopic composition. However, the proportions of the leach and residue leads in the pyrite are variable. This is shown in Figure 2 by the analyses of lead extracted from the unleached pyrite, which fall on a mixture line between the leach and residue end points. The unleached results indicate proportions of residue lead to leach lead ranging from 4.7 to 0.8. This is supported by isotope dilution results on one leach-residue pair which give 393 ppm residue lead and 151 ppm leachable lead, a ratio of 2.6. Further work is required to determine whether the homogeneous nature of the isotopic composition of the leach lead is a general phenomenon, since the assumption of compositional homogeneity introduces constraints on the interpretation of leach lead results. In particular, a homogenizing process prior to deposition of the leachable lead is required.

A leach-residue-unleached study on another pyrite, the O'Connor pyrite from the Timagami Lake area (sample 61 RF 0141, Appendix; Table A.3, B-1) was attempted. However, analytical problems due to low lead levels in both the leach and residue phases resulted in 3 residue analyses but only a single leach lead analysis. The residue composition appears to be homogeneous but the single analysis can give no indication as to the homogeneity of the leach lead composition.

Lead Contamination

Precautions were taken in the Geological Survey of Canada isotopic laboratories to minimize the contamination of sample lead with lead from reagents and the environment during the chemical extraction procedures. All extractions were done in a specially constructed clean laboratory using the most highly purified reagents available at the time. Blanks carried through the lead extraction and isotopic analysis procedures were shown to contain about one microgram of contaminent lead. Similar precautions were taken in the Isotopes Incorporated laboratories but we have no information on their contamination levels.

One microgram of contamination is insignificant in comparison with the quantity of PbS used for galena analyses, but may significantly affect the measured isotopic compositions of low lead, non-galena sulphides. If the result of the analysis of a low lead sample is unsupported by other data, the note "Low lead questionable" is applied. As estimates of the PbS yield for the samples analyzed by Isotopes Incorporated are not available, no comments are made on the lead level of these samples.

Mass Spectrometry

In the Geological Survey of Canada laboratories, isotopic abundances were determined on a ninety degree, ten inch radius, Nier type, solid source mass spectrometer. This instrument had a resolving power of about one part in three hundred which is sufficient to separate completely the peaks of the singly charged lead spectrum.

Lead ions were produced in the mass spectrometer by surface ionization from a single rhenium filament. Ion currents thus produced were scanned magnetically and amplified by an electron multiplier, detected with a vibrating reed electrometer and displayed on a pen recorder.

Each isotopic analysis consisted of twenty or more scans over the lead spectrum, each scan passing once up mass and once down mass through the mass range 203 to 209. Peak heights were measured from the recorder chart and an isotopic composition was calculated for each scan. These were averaged to yield the preliminary isotopic composition of the sample. This result was then corrected for recorder nonlinearity, and by factors directly proportional to the isotopic masses to compensate for source and electron multiplier discrimination in the mass spectrometer. The result thus corrected is referred to as "Raw Laboratory Data" in the tabulation of results. A further correction designed to normalize both the Geological Survey of Canada and Isotopes Incorporated results to absolute values is discussed in the following section.

Table 3. Conversion factors to change GSC data to absolute values

Isotopic % or Ratio	Absolute Values	GSC Value Average of 15 analyses	Conversion Factor GSC to Absolute
204	1.4689	1.4679 ± 0.0041	1.00068
206	23.513	23.461 ± 0.016	1.00222
207	22.617	22.604 ± 0.009	1.00058
208	52.401	52.467 ± 0.020	0.99874
206/204	16.007	15.983 ± 0.040	1.00150
207/204	15.397	15.399 ± 0.045	0.99987
208/204	35.675	35.743 ± 0.119	0.99810
207/206	0.96189	0.96347 ± 0.00082	0.99834
208/206	2.2287	2.2363 ± 0.0021	0.99656

Table 4. Conversion factors to change isotopes incorporated data to absolute values

Isotopic %	Conversion Factor	Isotopic Ratio	Conversion Factor
204	1.00613	$^{206}Pb/^{204}Pb$	0.99610
206	0.00223	$^{207}Pb/^{204}Pb$	0.99403
207	0.00016	$^{208}Pb/^{204}Pb$	0.99270
208	0.99883	$^{207}Pb/^{206}Pb$	0.99783
		$^{208}Pb/^{206}Pb$	0.99660

The Standardization of Data to an Absolute Reference

As the lead analyses reported herein were obtained at different times and by two laboratories, attempts were made to bring these measurements to a common standard as well as to standardize results to those of other investigators. To this end, numerous replicate analyses of standard Broken Hill galena (T-1003, Broken Hill No. 1, or UBC No. 1), as well as of several internal standards accompanied the analysis of the samples in question (Appendix; Table I).

For the bulk of analyses performed by the Geological Survey of Canada laboratory the average of 15 analyses of T-1003 were compared with corresponding "absolute values" published by Stacey et al. (1969). These data with corresponding derived conversion factors are presented in Table 3. Slightly different conversion factors will be obtained if the Cooper et al. (1969) values for T-1003 are used.

A similar procedure applied to the analyses from the Isotopes Incorporated laboratory yield the conversion factors which are listed in Table 4.

In addition, some analyses referred to in the text as being performed by the Geological Survey of Canada laboratory, were completed at a later date than the bulk of the analyses. These analyses generally were replicates of previously analyzed samples from both laboratories. Conversion factors, other than those listed above, consistent with contemporaneous analyses of T-1003 were applied as needed to these data.

Analytical Error

The two main sources of error that affect these analyses are mass dependent isotopic fractionation in the mass spectrometer and difficulty in measurement of the small lead-204 peak. Both of these can be estimated from the day-to-day variation of analyses of a particular sample about their mean. During the course of the Geological Survey of Canada analytical work reported here, fifteen analyses were performed on galena sample T-1003 (Broken Hill No. 1 galena standard). The errors associated with these results at the 95 per cent confidence level are listed in Table 5 as percentages. They were derived by multiplying the standard deviations of the results of the T-1003 analyses from their means by the factor 2.145 (Students' t table, 14 degrees of freedom).

Table 5. Percentage errors in isotopic analyses

Isotopic percentages	Isotopic ratios
^{204}Pb ± 1.2%	$^{206}Pb/^{204}Pb$ ± 1.0%
^{206}Pb ± 0.3%	$^{207}Pb/^{204}Pb$ ± 1.2%
^{207}Pb ± 0.2%	$^{208}Pb/^{204}Pb$ ± 1.4%
^{208}Pb ± 0.2%	$^{207}Pb/^{206}Pb$ ± 0.4%
	$^{208}Pb/^{206}Pb$ ± 0.4%

There is no direct method available for determining the error levels to be associated with the Isotopes Incorporated results. However, since the techniques used were the same as those used in the Geological Survey of Canada isotope laboratories, the error levels in their results are probably comparable. This is borne out by the fact that the scatter exhibited by the results produced by Isotopes Incorporated is about the same as that associated with the Geological Survey of Canada results. Errors associated with the factors derived to standardize the raw laboratory data are small and can be considered negligible with respect to the above error levels.

The Error Line

In addition to secondary isochron or binary mixing linear trends, lead isotope analyses exhibit analytical linear patterns which are referred to as "error lines". Most often seen in replicate analyses of a single sample, or in multiple analyses of samples of very similar isotopic composition, the existence of these linear patterns may be attributed to error

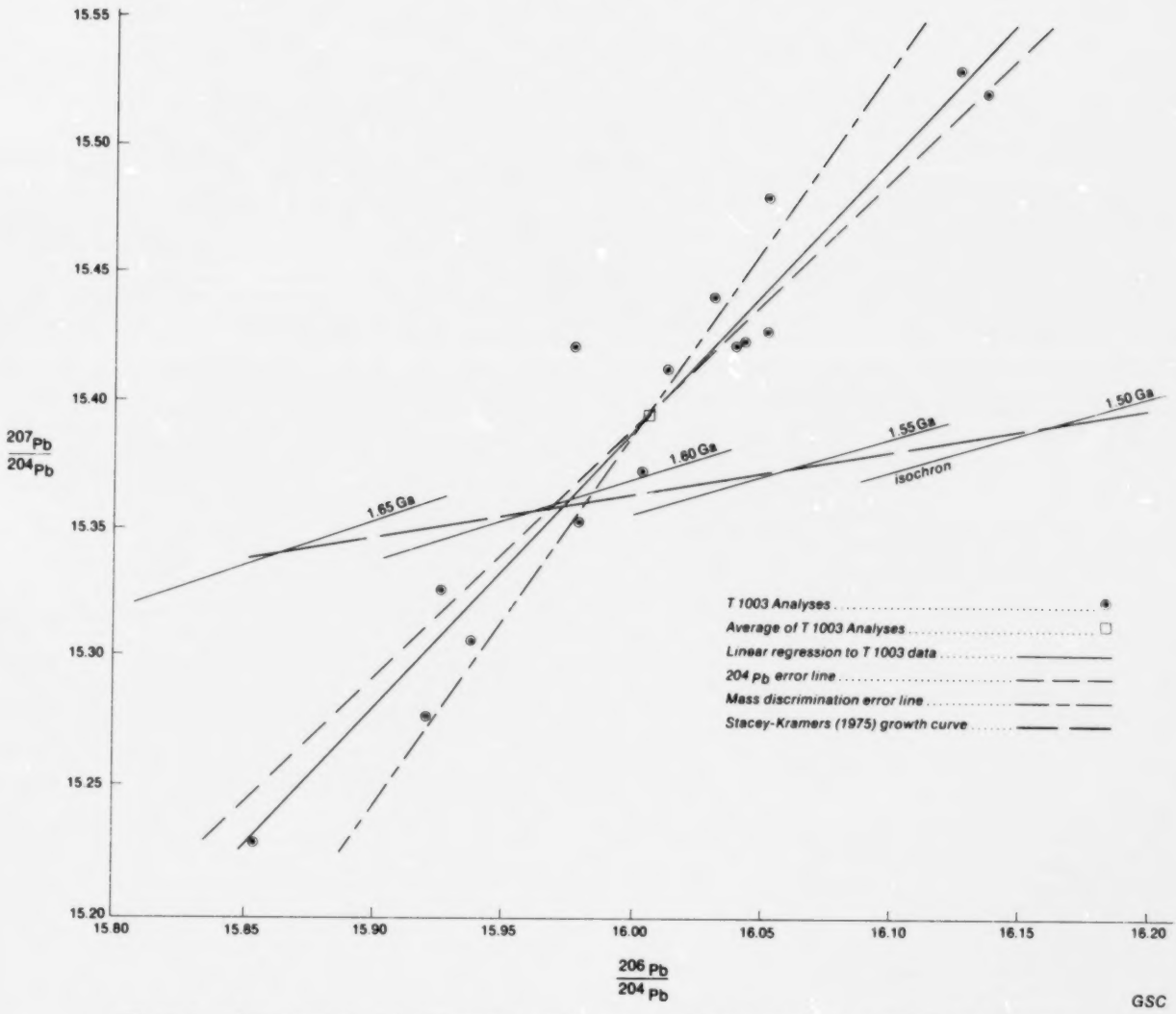

Figure 3. *Experimental and theoretical error lines. Replicate analyses of T1003, the standard galena, are used to calculate the slope of the experimental error line.*

in the measurement of ^{204}Pb the least abundant isotope, and to mass dependent fractionation of the lead isotopes in the mass spectrometer. ^{204}Pb error yields theoretical error lines with slopes equal to the $^{207}Pb/^{206}Pb$ ratio of the sample (^{204}Pb error lines); the slope of mass discrimination error lines will be 1.5 x the $^{207}Pb/^{206}Pb$ ratio. In practice, data points for replicate analyses would be expected to form a linear trend approximately bounded by lines with these slopes, as each analysis would be perturbed differently by the two effects.

Replicate analyses of reference sample T-1003 (Appendix, Table A.1) illustrate a typical "error line" (Fig. 3). The data are scattered about a line of slope 1.088, which is close to the theoretical ^{204}Pb error line slope of 0.962. The extent of the scatter closely approximates the envelope formed by the two theoretical error lines.

Although the data are distributed at a high angle to the isochrons (Stacey and Kramers model) on the diagram, similar data for older (e.g. Archean) common lead samples would fall in a trend close to the slope of isochrons in that older portion of the growth curve. In such cases, error lines could be mistaken for isochrons.

DEPOSIT CLASSIFICATION AND METHOD OF DATA PRESENTATION

The most useful system used to classify mineral deposits is a metallogenic classification. Unfortunately, considerable doubt exists about the origin of many types of deposits in the Superior and Southern provinces, thus preventing the formulation of a complete metallogenic classification. Indeed, one of the chief purposes of this study was to further the development of a comprehensive metallogenic classification for mineral deposits in the Precambrian Shield. An objective classification system has been developed for this study based on physical and chemical factors, including radiometric age determinations on host rocks. Genetic classification is generally avoided, unless a well accepted, clearly demonstrable origin has been postulated. The main requirement for this study is that lead

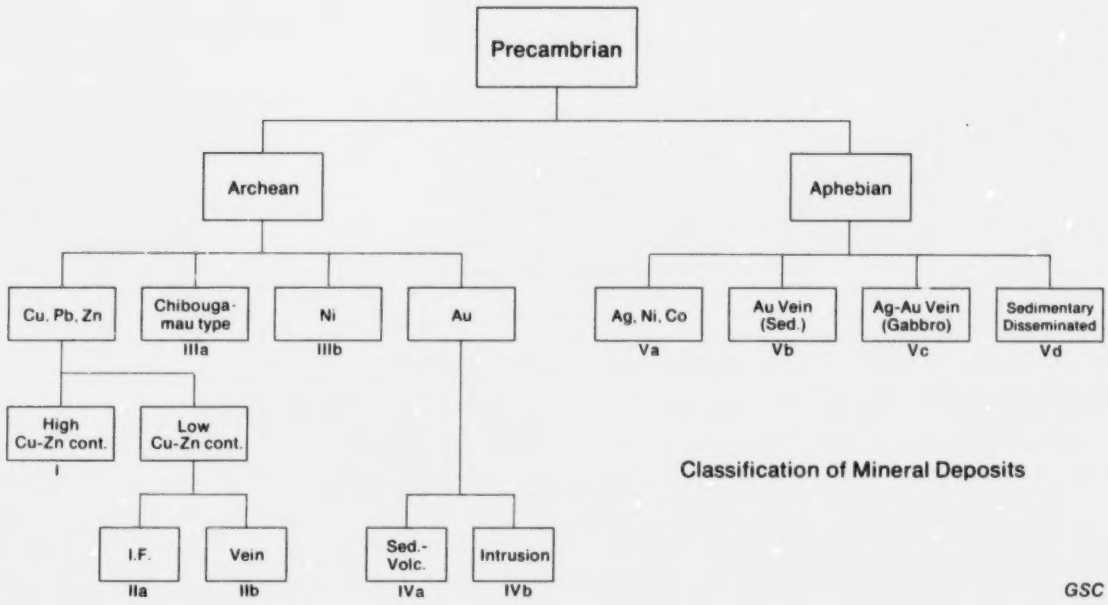

Figure 4. *Classification system for deposits in Superior and Southern Provinces.*

in a group of deposits with one specific history can be compared with lead in other deposit groups that may have had different histories. The parameters used here to establish such groupings are:

a. metal contained or recovered

b. structure of the deposit relative to its host rock

c. age and lithotype of host rock

d. existence of a distinct, spatially definable metal province.

The major groupings are shown in Figure 4, and are as follows:

A. Archean deposits: These are entirely hosted in Archean rocks, and have no lithological or structural evidence of post-Archean emplacement. The deposit types are:

I. Cu-Zn-Pb conformable, stratiform deposits; these include three volcanic-related exhalative massive sulphide deposits which contain economic or nearly-economic Cu and Zn.

II. Low Cu-Zn-Pb deposits include:

IIa. conformable, stratiform, iron sulphide deposits, commonly described as sulphide facies iron formations. Other iron formation facies, and pyritiferous sedimentary horizons are also included.

IIb. veins with minor Cu and Zn sulphides.

III. Intrusion-hosted deposits. These include:

IIIa. Chibougamau district, Quebec, vein and disseminated copper occurrences.

IIIb. mafic-and ultramafic-related nickel occurrences.

IV. Gold deposits: These include:

IVa. deposits hosted in supracrustal strata, including vein and bedded occurrences.

IVb. intrusion-related deposits, including vein deposits in intrusions, and vein deposits in the country-rock marginal to intrusions.

B. Aphebian deposits: these are entirely hosted in Aphebian rocks, or else in part cut Aphebian rocks. These include:

Va. Ag-Ni-Co vein deposits (Cobalt type).

Vb. Au veins in Aphebian sedimentary strata.

Vc. Ag-Au veins in Aphebian gabbro.

Vd. disseminated sulphide occurrences in Aphebian sedimentary strata.

Description of each deposit type will serve as an introduction to the presentation of lead isotope data, and is thus deferred.

Presentation and Interpretation of Data

As previously described, the samples have been grouped according to the classification of their respective deposits based on geological criteria. For each group, data tables (Appendix, Tables A.1 to A.5) are accompanied by a general description of the type deposit of that class, deposit location maps and a plot depicting the major isotopic trends along with their possible significance. Greater detail is provided by the large scale graphs (Appendix, Figures A.1 to A.5) in the pocket upon which each data point is separately represented. On these graphs, isochrons and selected growth curves, based on the Stacey and Kramers (1975) model, are shown.

An example of the format of the data tables employed in the text that follows, is depicted in Figure 5 with explanatory notes.

The descriptions are necessarily brief; pertinent references to more extensive descriptions are supplied for many deposits. Tonnage and grade data are supplied where available. Most of these data were current to 1978, and were obtained from the Canadian Mines Handbook (referenced as 'C.M.H.' in the tables), company reports, and private, non-confidential reports to the Geological Survey of Canada. Data for deposits in Quebec were obtained in part from Aramtchev and LeBel-Drolet (1979a, b) and various special publications of the Quebec Department of Natural Resources

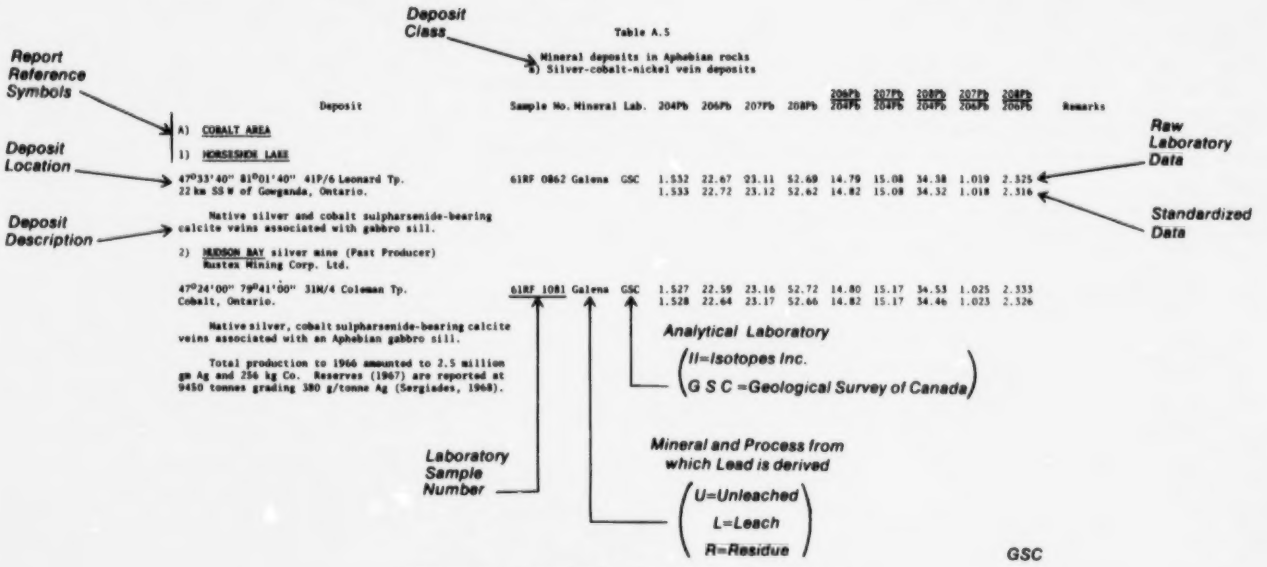
Deposit Class
Table A.5
Mineral deposits in Aphebian rocks
a) Silver-cobalt-nickel vein deposits
Report Reference Symbols
Deposit
Sample No. Mineral Lab. 204Pb 206Pb 207Pb 208Pb 206Pb/204Pb 207Pb/204Pb 208Pb/204Pb 207Pb/206Pb 208Pb/206Pb Remarks
A) COBALT AREA
Deposit Location
1) HORSESHOE LAKE
47°33'40" 81°01'40" 41P/6 Leonard Tp.
22 km SSW of Gowganda, Ontario.
61RF 0862 Galena GSC 1.532 22.67 23.11 52.69 14.79 15.08 34.38 1.019 2.325
1.533 22.72 23.12 52.62 14.82 15.08 34.32 1.018 2.316
Raw Laboratory Data
Standardized Data
Deposit Description
Native silver and cobalt sulpharsenide-bearing calcite veins associated with gabbro sill.
2) HUDSON BAY silver mine (Past Producer)
Rustex Mining Corp. Ltd.
47°24'00" 79°41'00" 31M/4 Coleman Tp.
Cobalt, Ontario.
61RF 1081 Galena GSC 1.527 22.59 23.16 52.72 14.80 15.17 34.53 1.025 2.333
1.528 22.64 23.17 52.66 14.82 15.17 34.46 1.023 2.326
Native silver, cobalt sulpharsenide-bearing calcite veins associated with an Aphebian gabbro sill.
Total production to 1966 amounted to 2.5 million gm Ag and 256 kg Co. Reserves (1967) are reported at 9450 tonnes grading 380 g/tonne Ag (Sergiades, 1968).
Analytical Laboratory
(II=Isotopes Inc.
G S C =Geological Survey of Canada)
Laboratory Sample Number
Mineral and Process from which Lead is derived
(U=Unleached
L=Leach
R=Residue)
GSC

Figure 5. *Example of data tabulation format.*

(e.g. Duquette, 1970 and Anonymous, 1967). A list of deposits and occurrences examined in this study (Appendix; Table A.2) is cross referenced to the text.

For each deposit or group of deposits, the data are examined to see if a 'single-stage' or 'multiple-stage' (anomalous) model should be applied. Single stage ages are calculated by the Stacey and Kramers model (1975), using equation 4. For coherent groups of analyses which illustrate an anomalous trend, R is calculated according to the two-error regression method of York (1969) and possible two stage calculations, including pertinent t_r, t_s, and $t_{r(max)}$ (t_s=0) and $t_{instantaneous}$ values are examined and evaluated.

DATA PRESENTATION AND INTERPRETATION

Group 1: Massive Sulphide Deposits of High Copper-Zinc Content in Archean Strata

Description

Stratiform, massive pyritic Cu-Zn-Pb sulphide deposits associated with volcanic rocks constitute a distinct ore type that has formed throughout geological time. They are commonly referred to as "volcanogenic" or "exhalative" massive sulphide ores in reference to their generally accepted mode of formation from submarine volcanic-derived emanations. Chemical sediments (including ore deposits) of predominantly volcanic exhalative origin have been termed "exhalites" (Ridler and Shilts, 1974, p. 1).

The term "massive" refers to mineralization composed of greater than 60 per cent sulphides and carries no strict textural connotation. In deposits in Archean rocks the principal economic minerals are chalcopyrite and/or sphalerite, but many deposits also contain economic concentrations of silver and/or gold. Lead, in the form of galena, is recovered from very few Archean massive sulphide deposits, a reflection of the normally low-lead constitution of these deposits. The Coniagas, Geneva Lake and Stralak deposits are compositionally unusual in that they are principally zinc-lead deposits with low copper although all have most of the essential morphological features of a massive sulphide deposit. The Geneva Lake deposit is highly metamorphosed and deformed, cut by dykes of granite from a nearby pluton, and has both highly recrystallized massive sulphide ore and crosscutting remobilized sulphide-rich veins. Also, some zones in the Kidd Creek mine (Texasgulf Ltd.) are also of the zinc-lead type.

The main geological features of massive sulphide deposits have been presented elsewhere by Sangster (1972a). Many such orebodies are composed of two ore types: a layered conformable, high sulphide content, Zn-rich portion and a stratigraphically underlying discordant, low-sulphide content, Cu-rich portion consisting of veins or disseminations. The small amount of galena found in Archean deposits normally occurs in the layered Zn-rich portion of the orebodies. The discordant, Cu-rich 'stringer-zone' is characteristically enveloped within a zone of altered host rocks and the entire stringer zone and alteration envelope is considered to represent the pathway through which mineralizing solutions passed en route to forming the conformable, exhalative deposits above. Franklin et al. (1975) have shown, by chemical means, that this footwall alteration can be much more extensive than would appear from casual visual examination of the wall rocks. This suggests that the metals for formation of the massive sulphide deposits could have been derived by leaching of the footwall host rocks.

Deposits in Group 1 range in size from a few hundred thousand to over 100 million tons, in metamorphic grade from greenschist to sillimanite facies, and in total lead content from perhaps only a few hundred parts per million to a few per cent.

Whether the origin is by leaching of footwall rocks or primary derivation from an underlying magmatic hearth, volcanogenic massive sulphide deposits are considered to be coeval and cogenetic with their enclosing volcanic strata. Furthermore, all Archean deposits considered in this paper have been metamorphosed to varying degrees by the Kenoran orogeny which is considered to have climaxed at approximately 2560 Ma* (Stockwell, 1973).

Interpretation

Data for Group 1 are listed in Appendix Table A.1, and plotted on a large scale graph (Appendix, Fig. A.1, in pocket). Deposit locations are shown in Figure 6, and major trends are summarized in Figure 7.

* "U-Pb scale" age, using decay constants of Jaffey et al. (1971).

Fifty-three analyses of samples from massive sulphide deposits in the Abitibi belt (Fig. 6) plot within a tight cluster elongated along a trend with a $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ slope near 1.0 (Trend 'a', Fig. 7). The remaining analyses plotted in Figure 10, which include three galena samples from the Kam Kotia deposit, and eight from deposits in the Geneva Lake-Stralak greenstone segment, lie within a branching trend 'b' with a much lower $^{207}Pb:^{204}Pb/^{206}Pb:^{204}Pb$ slope. Trend 'a' is subparallel to a ^{204}Pb error line, and a cursory inspection of these data might suggest that it reflects ^{204}Pb errors in analyses of a single ordinary lead and that trend 'b' resulted from additions of radiogenic lead to several deposits that initially contained this ordinary lead only. The spread shown by trend 'a', however, is greater than that expected by ^{204}Pb error (see T1003 replicate analyses, Fig. 1), and detailed examination of the data as outlined below

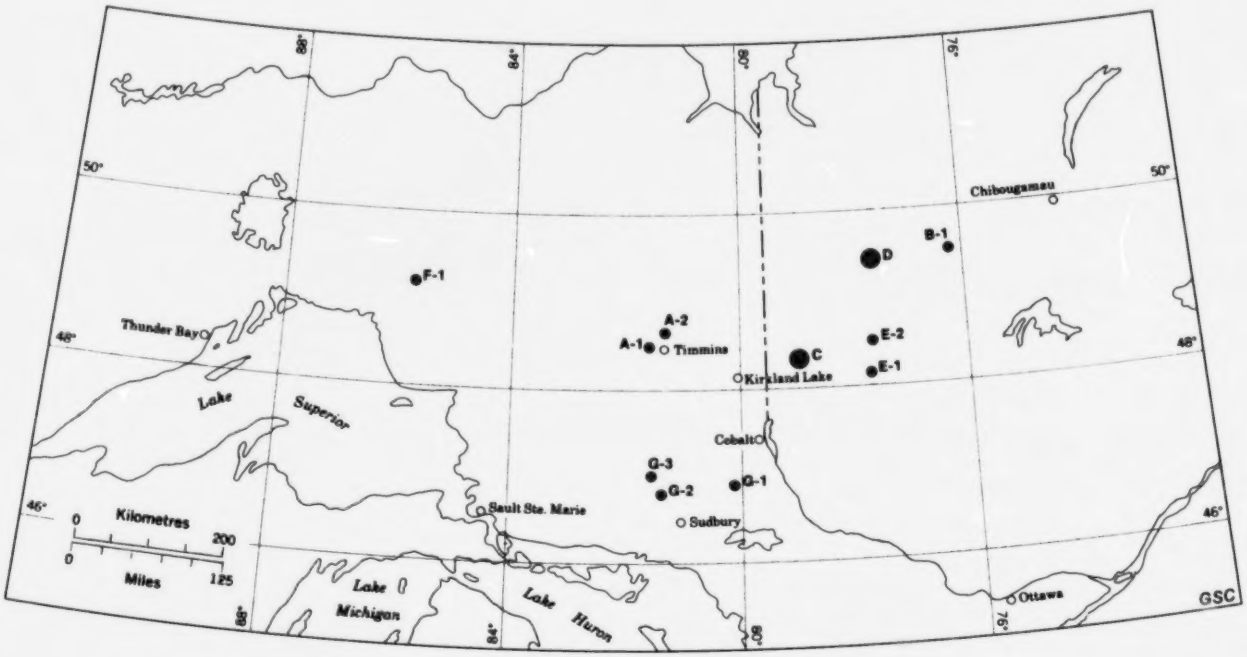

Figure 6. *Group 1 deposit locations: Massive sulphide deposits with high copper-zinc contents in Archean strata.*

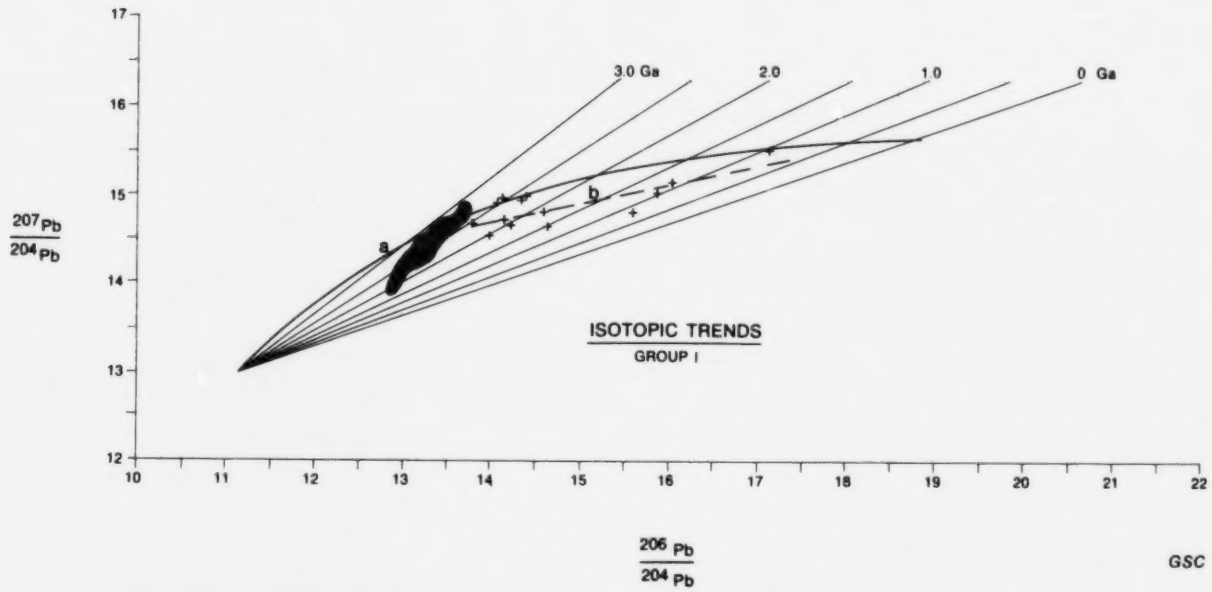

Figure 7. *Group 1: Major isotopic clusters and trends in massive sulphide deposits with high copper-zinc contents.*

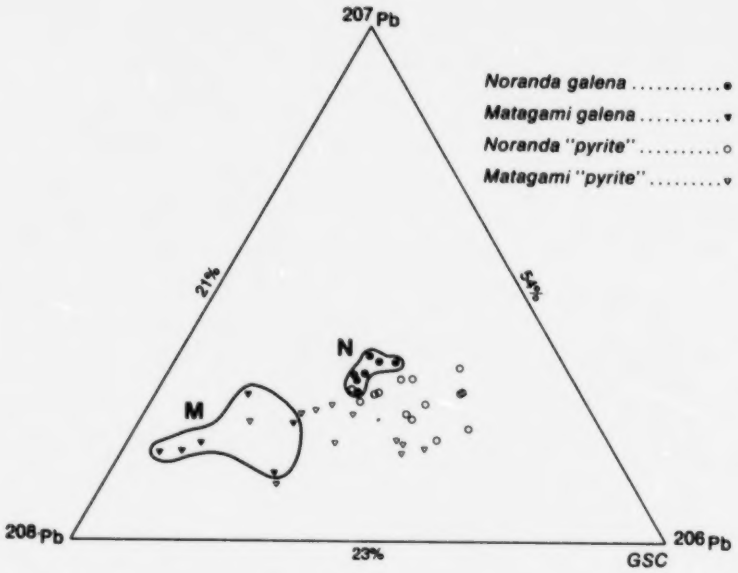

Figure 8

Ternary diagram of the radiogenic components of Matagami (M) and Noranda (N) galena and nongalena (labelled "pyrite") samples.

establishes that several compositions of ordinary lead are present. These were developed in systems with different U:Th:Pb ratios. Some may also have been formed at slightly different times.

Twenty-four galena samples (including replicates of a single sample) were selected as typical of massive sulphide deposits. Samples from Stralak and Geneva Lake are excluded, as possible remobilization of lead and consequent radiogenic lead contamination make them unsuitable as "typical" deposits. Furthermore, samples from Quemont and Horne are discussed with the Group II deposits, as these galena samples are from veins.

The elongate cluster lies almost entirely below the 'best-fit' growth curve (μ = 9.74), indicating that the massive sulphide lead in Superior Province formed in a uranium-poor environment. It has a centroid composition (Table 6) which yields a Stacey and Kramers model age of 2708 Ma (μ = 8.19). The elongation is partly due to analytical errors, but some real variation in composition is present, as analyses of a group of samples of a single composition should lie within a much smaller field (see T1003 replicate values, Fig. 3). Also, should analytical error be the principal cause of variation in the data, the elongation would have a significantly steeper slope, corresponding to the $^{207}Pb/^{206}Pb$ ratio in the samples. Thus the data variations are due at least in part to age differences and/or to differences in μ.

In order to eliminate effects of ^{204}Pb errors, the radiogenic isotopes (^{206}Pb, ^{207}Pb, and ^{208}Pb) are normalized and plotted on a ternary diagram (Fig. 8). Here, galena samples from individual mining camps as well as those from individual deposits lie in very tight clusters. Six galena analyses from the Matagami camp (three analyses on each of one Mattagami Mine and one Orchan Mine sample) form a cluster (M) well separated from a tighter cluster (N) of analyses of seven galenas from six separate Noranda camp

Table 6. Compositions and model ages of selected data groups. Group I and Group IIB deposits

Deposit or District (no. of samples)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Model ages (Ma) Stacey-Kramers	Cumming-Richards
Noranda galena (7)	13.273	14.457	33.094	2728	2779
Mattagami galena (2)[1]	13.195	14.415	33.282	2754	2810
Noranda non-galena (15)	13.247	14.357	32.891	2552	2719
Mattagami non-galena (11)	13.203	14.321	32.946	2536	2727
Average galena (15)[1,2]	13.249	14.445	33.137	2739	2788
Average non-galena (34)	13.268	14.364	33.003	2537	2705
Median galena (24)[1,2]	13.23	14.45	33.10	2774	2810
Median non-galena (34)	13.25	14.37	32.96	2578	2727
Centroid galena (24)[1,2]	13.226	14.415	33.096	2708	2785
Centroid non-galena (34)	13.269	14.367	32.995	2544	2707

[1]Replicate samples averaged before these average values were calculated.

[2]Geco, Kam Kotia and clearly anomalous values excluded.

deposits (Horne, Lake Dufault, Amulet A and C, D'Eldona and Dumagami). Computations using mean values for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios of lead that plots within these two clusters (Table 6) indicate that galena isotopic compositions in Noranda deposits compared with those in Matagami deposits developed in a system with (1) distinctly lower Th:U ratios and (2) slightly higher U:Pb ratios, and (3) appear to have been deposited about 30 million years later. Analytical uncertainty in the individual analyses comprising the averages reduces the probability that there is a real difference in ages of deposits in the two areas.

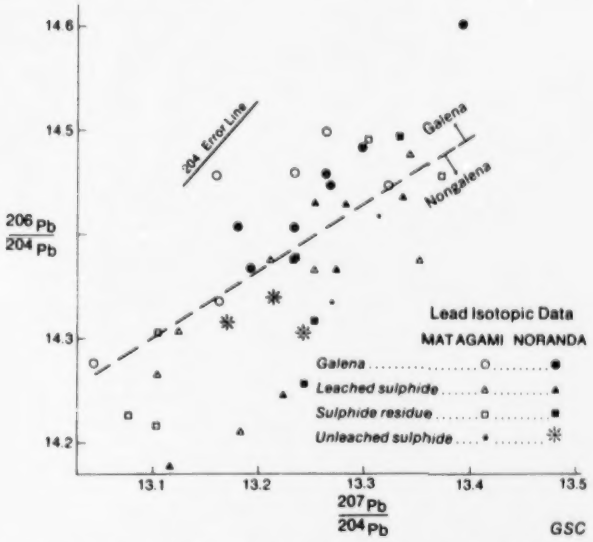

Figure 9. *Comparison of galena and nongalena lead isotopic compositions for the Noranda and Matagami areas. Note that the nongalena analyses are shifted to a lower $^{207}Pb/^{206}Pb$ position, indicating a different source of lead for these samples.*

Analyses of trend 'a' galena samples from other massive sulphide deposits in the Abitibi belt, Kidd Creek, East Sullivan, Barvue, Normetal and Coniagas, have $^{206}Pb:^{207}Pb:^{208}Pb$ compositions either within the same field as those of the Noranda camp galena samples or compositions which are intermediate between the Noranda and Matagami fields. Although in all cases age differences might explain some of the compositional differences, the probability that the lead for each camp was generated in a distinctive U/Th/Pb environment is evident.

The model ages are close to the $^{207}Pb/^{206}Pb$ minimum ages of single zircon concentrates of 2668 Ma, determined on the Flavrian intrusion, and 2666 Ma determined on the Quemont Hill rhyolite porphyry (W.D.L., 1980). They also conform closely to the Rb/Sr data reported by Dey-Sarkar (1971), to the zircon age of 2710 Ma of Krogh and Davis (1971) on Noranda rhyolite, and to the 2680 Ma age determined by Steiger and Wasserburg (1969) on the Preissac-Lacorne and similar intrusive rocks of the region.

The second group of 'common' leads which comprise cluster (a) is made up of 31 samples which contained lead as a trace constituent. Pyrite is the most common mineral of this group, but sufficient lead was also found in sphalerite, chalcopyrite, and pyrrhotite to allow for analysis. This suite of samples forms a cluster similar to the galena cluster, but this cluster is shifted to a lower $^{207}Pb/^{204}Pb$ and higher $^{206}Pb/^{204}Pb$ position, relative to the galena data (Fig. 9 and Table 6). The non-galena cluster also is broader than the galena cluster. The lead in the non-galena cluster thus has a different genetic history, which is further demonstrated by examining the distribution of radiogenic lead in the Noranda and Matagami samples (Fig. 8).

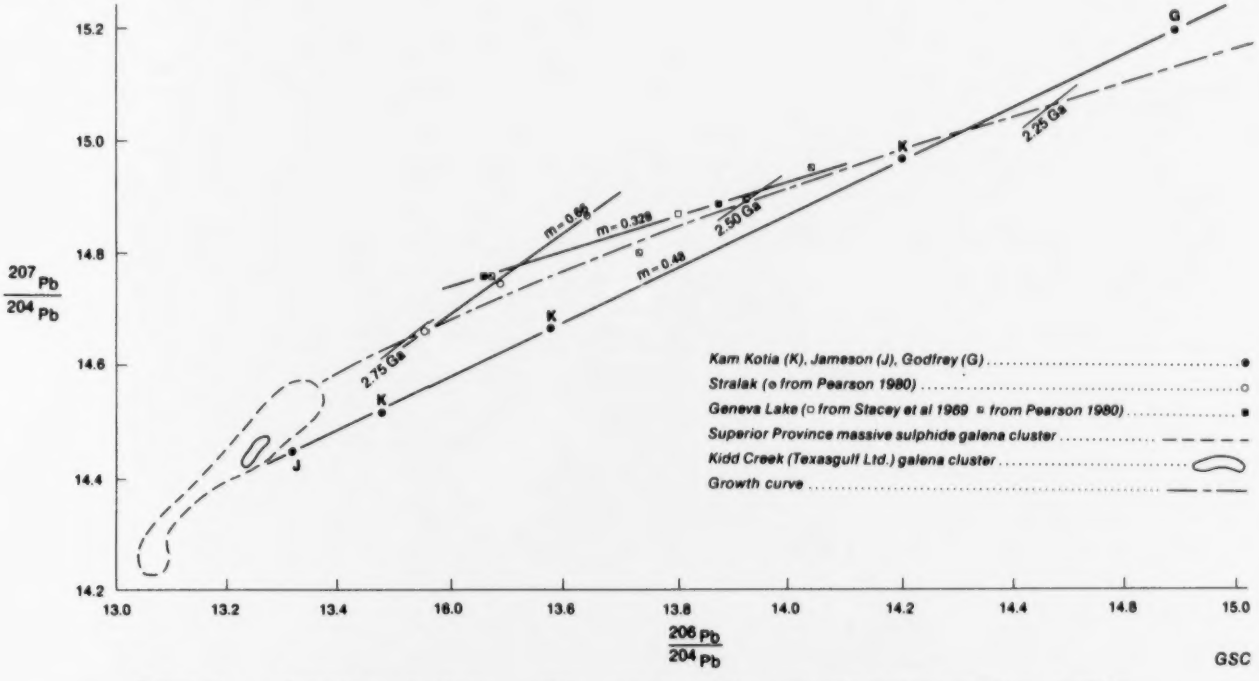

Figure 10. *Secondary isochrons, galena samples only, volcanic-hosted massive sulphide deposits, Superior province.*

The specific galena clusters for Noranda and Matagami samples have corresponding non-galena clusters (Fig. 8 and Table 6). In both cases the latter clusters are (i) shifted towards the $^{207}Pb/^{206}Pb$ join, and (ii) have only minimal overlap with the galena data. The non-galena data yield relatively younger model ages (Table 6), but their relatively low μ values suggest growth in a secondary low μ system, which renders these model ages suspect.

Barring systematic analytical errors, the data are highly significant in terms of the origin of the trend in the galena versus non-galena samples. Radiogenic addition to the galena composition will not explain the shift of the non-galena population, as such additions should yield higher $^{207}Pb/^{204}Pb$ ratios, not the observed lower ratios. Thus the non-galena samples must have obtained their lead from a separate system which, in both the Noranda and Matagami camps, had less radiogenic lead than the system which produced the galena lead. Lead must have been extracted penecontemporaneously from two different U:Th:Pb systems.

Trend (b) encompasses data from the Geneva Lake-Stralak and Kam Kotia areas, each of which form subparallel arrays that can be interpreted as secondary isochrons (Fig. 10). Additional, more recent (and more precise) data are also shown on this figure (Pearson, 1980; Stacey et al., 1969). Geneva Lake lead isotope data have been, in most recent studies, used as one of the data points to fix the position of the 'model curve' (Stacey et al., 1969; Cumming and Richards, 1975; Stacey and Kramers, 1975). This deposit is similar in many respects to a typical volcanogenic massive sulphide deposit, but it is cut by numerous granitic dykes and metamorphosed by an adjacent Kenoran granitic body. Inspection of our data, plus those of Stacey et al. (1969) and Pearson (1980) indicate that several of the galena samples form a cluster that yields a model age of approximately 2790 Ma (μ = 10.7). The high μ value indicates that the lead was formed in an environment that was very uranium-rich relative to the Noranda and Matagami Lake camps; this further illustrates the variation in uranium/lead ratios in the lead generative environment between areas in the Superior Province.

The remaining data are spread along a secondary isochron, with a slope of R = 0.32. These anomalous compositions are probably the result of the addition of radiogenic lead to the common lead, as represented by the cluster of compositions with the 2790 Ma model age. This addition may be due to metamorphism and redistribution of the sulphides by either the adjacent Kenoran granite, the nearby Nipissing diabase, or some event related to emplacement of the Sudbury intrusion.

Assuming an age of mineralization (and thus of volcanism) at some time during the period of 2650 to 2750 Ma, the radiogenic component was generated between this period and 1850-2000 Ma and added during the latter period. This age is slightly younger than any Aphebian event manifest in the area, but it may be related either to the emplacement of the Nipissing diabase, the Sudbury intrusion and associated breccias, or to an early Penokean orogenic event.

The Stralak deposit occurs in the same volcanic sequence as the Geneva Lake deposit, but its lead isotopic characteristics are somewhat different. Averaging the data for each of the samples of 65RF005 and 65RF004, and including one additional analysis (Pearson, 1980) yields a relatively high μ (9.9 and 10.3) and similar (2754 Ma and 2737 Ma respectively) model ages, indicating the data are distributed close to an isochron of the Stacey and Kramers' model and are on a secondary isochron of slope R = 0.66.

The value of the additional high precision data of Pearson (1980) must be emphasized, as this confirms that an otherwise tenuous two-point line is really a secondary isochron.

The isotopic inhomogeneity in this deposit is unusual as most deposits of this type exhibit remarkable lead isotopic homogeneity. The relatively high μ of the lead is the result of the addition of variable amounts of a radiogenic component, either during metamorphism, or during initial deposition of the galena. If the former, the high slope (0.66) requires that metamorphic re-equilibration at 2500 Ma (Kenoran) would necessitate a source rock of 3900 Ma. This presumably would be basement rock to the greenstone belt. If this were the case, then metal transport must have occurred in a relatively poorly mixed, and probably dilute, solution. Perhaps the deposit may not be a volcanogenic massive sulphide deposit, but may have been formed by percolating, gravity-driven intrastratal water, in a manner similar to that prescribed for sandstone-type Zn-Pb deposits.

The third set of data which comprises part of trend (b) is from the Kam Kotia deposit, and includes both galena and pyrite analyses. All samples yield model ages of less than 2600 Ma, which are meaningless, as the data clearly form a secondary isochron. The lead-isotopic composition of the pyrite leach-residue pair indicates a primitive composition: the leached lead analysis plots in the main Superior Province massive sulphide cluster, and the residue analysis plots on an error line below the cluster. The pyrite data are excluded from the secondary isochron calculation. The galena samples form an anomalous line with slope 0.49. Although more data are necessary to give greater confidence in the slope determination, several models may be tested.

The Kam Kotia array coincides with a line between isotopic compositions of galenas in veins in Jamieson and Godfrey Townships (Appendix, Table A.2(b), deposits G1, G2) not far from the Kam Kotia and Genex deposits. The Kam Kotia occurrences are in part vein-like concentrations formed (or redistributed) subsequent to volcanism and primary ore deposition. They probably contain lead secreted from the sulphide deposit and mixed with other lead. The secondary isochron, including the two fracture-controlled occurrences and three Kam Kotia galenas, has a slope of R = 0.48. It crosses the centre of the main cluster of Archean gold deposits and projects into the massive sulphide cluster, very near the isotopic composition of the Kidd Creek deposit (Fig. 10). It should also be noted that most occurrences of galena in gold and other veins in Archean pre-Kenoran(?) intrusions have isotopic compositions that fall within a narrow belt near this line and its extension (see Fig. 23). Thus the R = 0.48 secondary isochron appears to reflect a most important phenomenon. This was most likely the mixing of either pre-volcanic lead or synvolcanic lead with later radiogenic, or perhaps ordinary, lead prior to or during the Kenoran Orogeny. $T_{instantaneous}$ for R = 0.48 is 2.8 Ga, so the one component must be older than this, the other younger. Including the Kidd Creek data in this calculation causes the slope to change to 0.456, giving a $t_{instantaneous}$ of approximately 2.77 Ga.

If the mixing occurred during the Kenoran Orogeny no more than 2.6 Ga ago, then the older lead must have been formed no less than 3.0 Ga ago. This presumably would have to have been in pre-volcanic basement rocks as yet not identified in this region. Alternatively the radiogenic lead was generated in a short period of time 2.77-2.8 Ga ago. This would suggest that most of the volcanic rocks and penecontemporaneous intrusions are slightly older than Rb/Sr and U/Pb dates elsewhere in the Abitibi belt, such as a zircon U/Pb date of 2710 Ma on rhyolite near Noranda (Krogh and Davis, 1971).

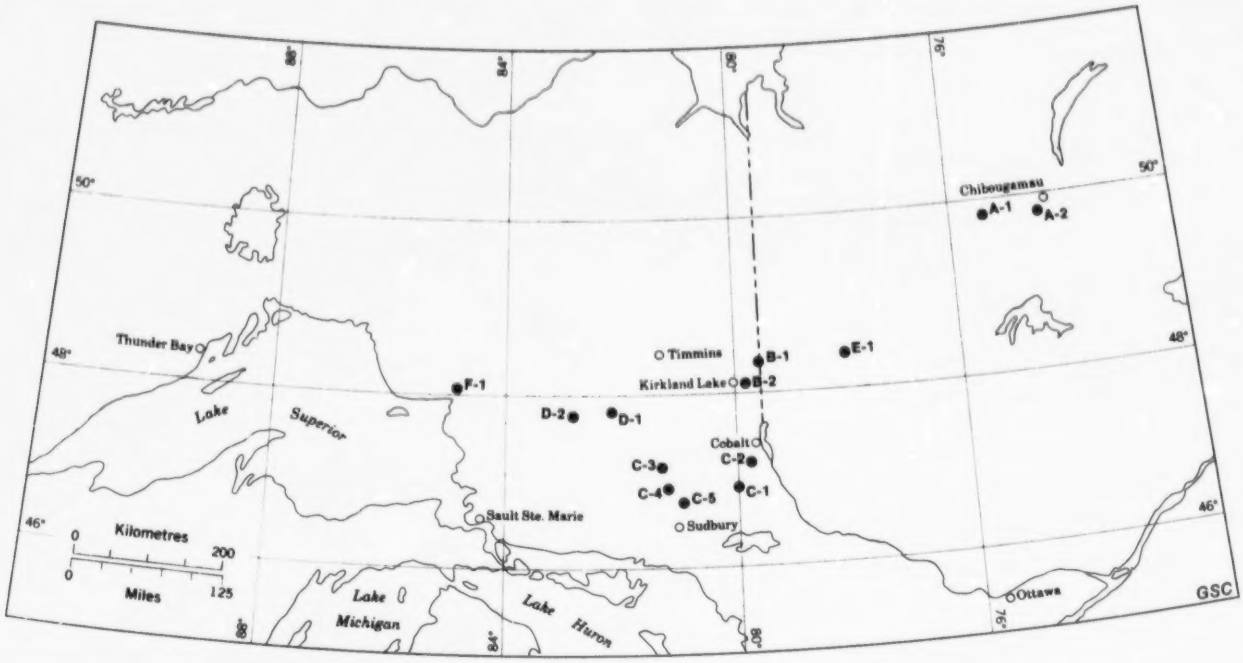

Figure 11. *Group IIa deposit location; Archean volcanic-and sedimentary-hosted stratiform low base metal (pyritic) deposits, with low Cu-Zn contents.*

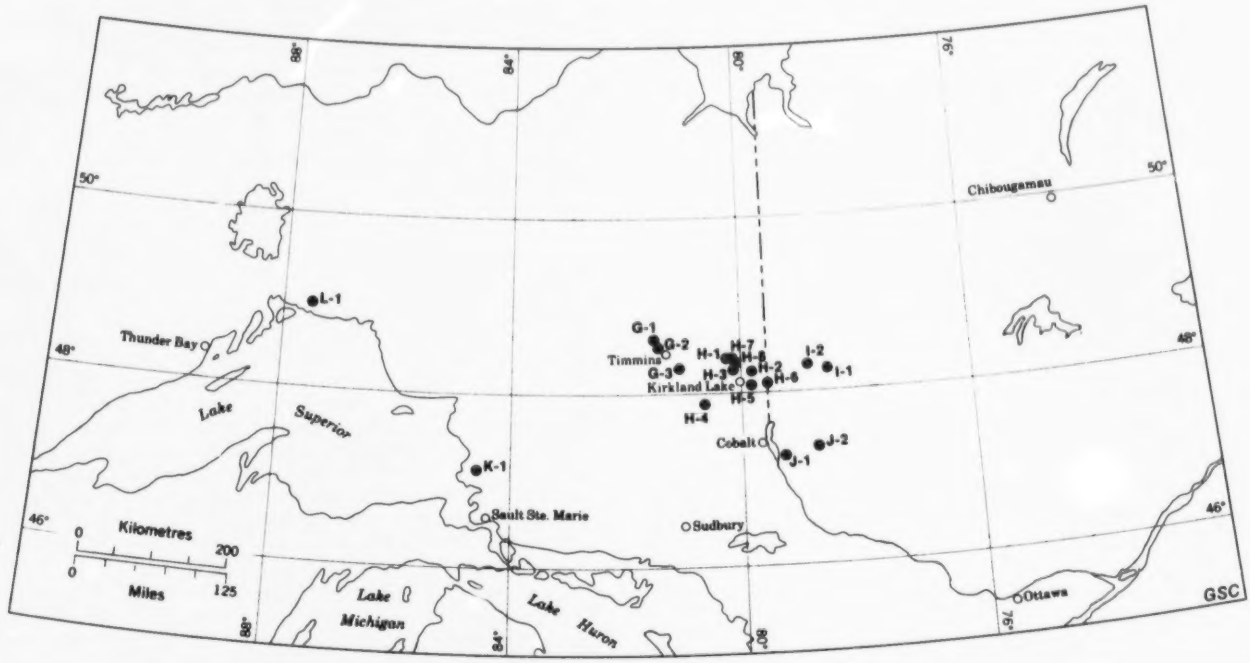

Figure 12. *Group IIb deposit locations; Archean volcanic and sedimentary hosted vein-type low base metal deposits.*

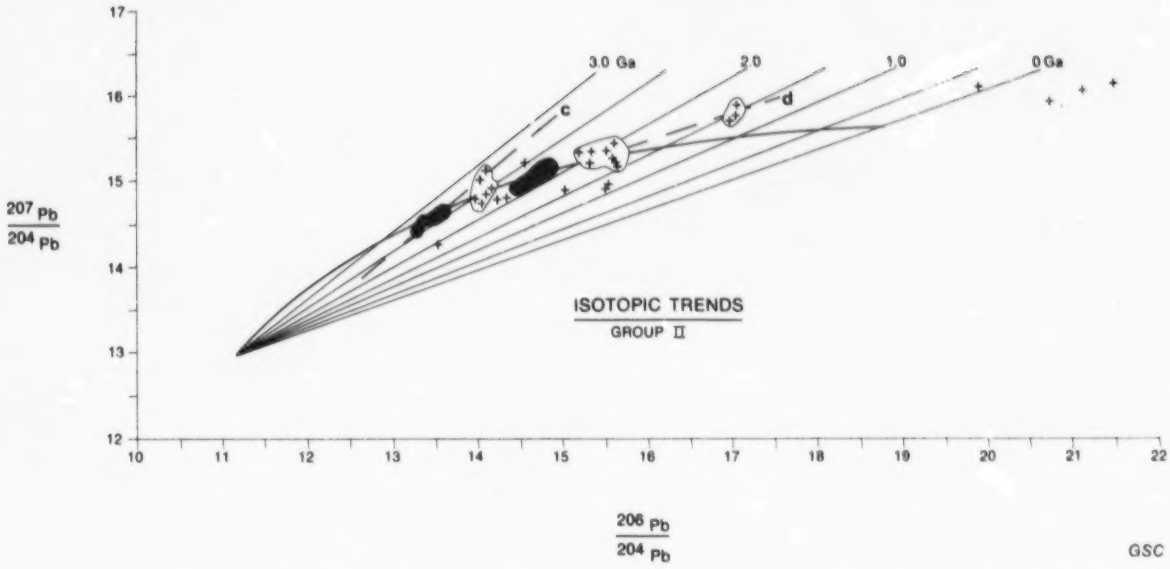

Figure 13. *Group II major isotopic clusters and trends; low base metal stratiform and vein-type deposits.*

Group II: Massive Sulphide Stratiform and Vein Deposits with Low Base Metal Contents

In an attempt to isolate the effects of post-volcanic events, samples were collected from two classes of sulphide-bearing deposits which are of little economic significance due to low copper, zinc, lead and silver contents yet have reasonably close spatial affinities and/or structural similarities to higher grade Cu-Zn deposits of high economic value. The two types of deposits are: (a) pyritic stratiform deposits that contain little, if any copper and zinc, and (b) pyritic-quartz-carbonate veins.

Data for Group II are listed in Table 2 and plotted on a large scale graph (Appendix, Fig. A.2). Deposit locations are shown in Figure 11 (stratiform deposits) and Figure 12 (vein deposits). Major trends evident in the data are summarized in Figure 13.

(a) Pyritic Stratiform Deposits with Low to Very Low Cu-Zn Contents

These deposits are generally enclosed in thin, laterally extensive supracrustal strata, are rich in pyrite and pyrrhotite, exhibit a considerable range of lithologic affinities, and occur as three main types:

i) sulphide lenses and layers interlayered with chemical and clastic sediments; oxide facies iron formation is present in some (Rush Lake, Peter Lake, Adams, Pitcher Mobi); chert or cherty tuff (Marshay Tp., Marbridge) in other deposits indicate that silica was a significant non-sulphide exhalative product;

ii) disseminated to massive pyrite bodies in tuff (Kitchener, Botha);

iii) disseminated to massive pyritic bodies with sub-economic Cu-Zn content, within rhyolitic pyroclastic rocks, commonly near overlying mafic flows. These deposits are similar to the massive sulphide deposits of Group I, but are enriched in iron relative to copper and zinc, and are noneconomic due to grade limitations (e.g. Roche).

Some deposits bear characteristics of all three of the above types. As the primary characteristic is the relatively high iron content, these bodies are generally classed as "sulphide-iron formation type".

(b) Pyritic Quartz-Carbonate Veins

Included in this deposit class are veins which clearly crosscut Archean strata and associated gabbroic and dioritic intrusive bodies. The latter bodies (e.g. the Jameson Tp. and Dane occurrences) may be subvolcanic in origin as they occur within volcanic strata, are fine grained, and are chemically similar to andesites. The locations of the vein-type deposits are shown on Figure 12.

The veins vary from narrow, quartz-rich stringers (e.g. Joannes Tp.) to a more common quartz-carbonate variety (e.g. Benoit Tp.). A few contain subeconomic ore tonnage (e.g. Matarrow) or are spatially associated with (past) producing deposits (e.g. Quemont vein, Lorrain vein). The Tribag deposit is the only breccia-pipe vein system examined.

Although all deposits in Group II(b) are contained totally or largely within Archean strata, it is important to note that several have mineralogical or spatial characteristics which lead to possible interpretation of an affinity with younger deposits. For example, the Lorrain vein bears many characteristics of Cobalt-type silver veins (Petruk, 1971), and the Pays Plat vein is similar to the Pb-Zn-Ba veins associated with the Helikian Sibley Group (Franklin and Mitchell, 1977). The Tribag deposit, although contained within Archean granite, is associated with Helikian volcanic rocks (Wanless et al., 1967) and both cuts and is cut by a Helikian dyke (785 ± 103 Ma, K-Ar). This indicates that this deposit formed considerably later than the Archean (Wanless et al., 1966).

Interpretation, Low Base Metal Massive Sulphides

The data summarized in Figure 13, may be divided into two generalized trends, 'c' and 'd'.

Trend 'c' is composed of data from residues of a Temagami pyrite sample after laboratory leaching, galena from the Roche and Mammouth stratiform bodies, and galena from the Black Township veins. The Temagami data are discussed later in conjunction with the leached and unleached pyrite data.

The galena data in trend 'c' probably represent spread along an error line, with an average model age (Table 9) of 2757 Ma (μ = 10.21). This calculated age is essentially similar to the age of the majority of the samples from base-metal-rich deposits, and is close to the age established for the volcanic rocks of the Abitibi region. The relatively high $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ position of the Mammouth data may have caused the model age to be somewhat erroneous.

Trend 'd' represents a family of secondary or anomalous lead lines originating from the cluster of 'common' leads of group 'c'. These deposits include most of the vein deposits and many of the leached and unleached pyrite samples.

Temagami Mine Road Occurrence

These 14 analyses of various portions (leach, unleached and residue) of a single sample illustrate the potential usefulness of analyzing trace lead contents of pyrite. In total, the analyses lie on an apparent secondary lead line ($^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$) of slope 0.293 ± 0.043 (Fig. 14). This anomalous line (see also Fig. 2) is made up of three components, (1) the unleached samples which form the major linear portion of the line, (2) the acid-leached portions which form the most anomalous portion of the line, and cluster at a model age of 1670 Ma, and (3) the compositions of the residue portions which lie in the 2700 Ma cluster of compositions of trend 'c' (Fig. 13) and are similar to the galena compositions of the conformable base metal deposits of trend 'a' (Fig. 7) and thus have model ages which correspond to the age of Archean volcanism.

Although several interpretations of this line are theoretically possible, we are constrained by the remarkable homogeneity of each of the leach and residue lead isotope compositions. Clearly the anomalous line results from mixing of variable amounts of the leach component with the residue component.

The average residue component yields a model age of 2707 Ma (μ = 9.31), which is consistent with the age of most of the volcanic strata and volcanogenic massive sulphide deposits in the Abitibi belt. Thus the lead was initially deposited as a homogeneous component in pyrite at about 2707 Ma and was probably derived from the andesitic host rocks.

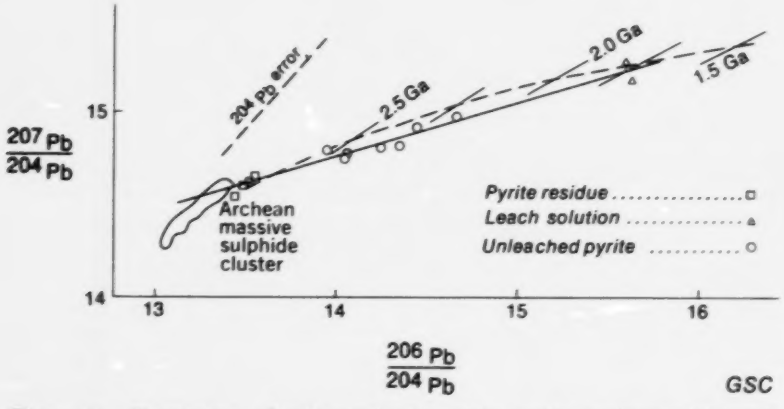

Figure 14. Comparison of unleached and residue pyrite analyses with leach solutions for pyrite from Temagami Mine Road occurrence (61 RF 388).

The average leach component yields a model age of 1670 Ma, with μ = 9.31 which is the same as that for the residue. One hypothesis for the source of the leach component, supported by the similarity of μ values, is that uranium and thorium in the andesitic host rocks continued to produce the radiogenic lead isotopes after the intimate incorporation of the residue phase lead into the pyrite at 2707 Ma. At 1670 Ma lead was again extracted from the andesites but at this time emplaced surficially on the pyrite. The additional radiogenic component which had accreted from 2707 to 1670 Ma provides the younger isotopic signature of the leachable lead. In this system, both residue and leach leads can be considered as ordinary or common leads.

Other solutions involve splitting the leachable lead into two theoretical components; a primary common lead component of Archean age, and a secondary radiogenic component. If the primary component is assumed to have the same isotopic composition as the residue phase from the pyrite, then the mixture line between the two pyritic phases may be treated in a manner analogous to an anomalous lead line or secondary isochron. If this is not the case, the primary component will generally not fall on the mixture line, and any calculations made must refer to the slope of a new line joining the assumed composition of the primary component with that of the total leachable phase.

It seems rather certain therefore, that significant movements and recombinations of lead occurred around 1670 Ma in the Timagami area, related in some way to the Hudsonian Orogeny. This is remarkable as no important geological event, let alone pervasive metamorphism, is known to have occurred in the Timagami area at this time. Evidence for such events should be sought. The most relevant phenomena and age data are: intrusion of Sudbury Irruptive 80 km southwest (1842 Ma, Hurst and Farhat, 1977); the "Sudbury breccia dykes" (1704 ± 194 Ma, Hurst, 1975); the New Delhi prospect 30 km northwest of Timagami which contains homogeneous lead with a model age of 1809 Ma (Appendix, Table A.5); K-Ar dates of 1700-1500 Ma through and near the Southern province; and evidence for possible episodic loss of lead from radioactive minerals in the Southern province around 1700-1500 Ma ago (Roscoe, 1969, p. 147-158).

Kirkland Lake Veins

A second group of deposits which form parts of trend 'd' (Fig. 13) are the Kirkland Lake vein deposits (Fig. 15). The veins occur in various Archean volcanic and sedimentary rocks. Most are rich in galena and sphalerite and have a quartz-carbonate gangue. The Matarrow, Dane, Lowe and Wolf Lake occurrences are each close to an alkalic stock or batholith (R.H. Ridler, personal communication, 1975) which are abundant in the Kirkland Lake and Matachewan areas, but relatively uncommon in other areas of the Superior Province. The Black Township., St. Pierre, Solmes, and Benoit occurrences, however, are not spatially related to large alkalic bodies. The area is partially overlain by rocks of the Cobalt Group and probably was entirely covered by this unit during the post-Aphebian portion of the Precambrian. The vein genesis is obscure but derivation from alkalic source rocks directly, by metamorphism (contact or regional), or possibly by leaching of the Cobalt sedimentary rocks, are possibilities worth examining in light of the regional geology.

Galena samples from Wolf Lake, Matarrow, Dane, and Lowe occurrences have a narrow range of isotopic compositions and form a cluster along an error line (slope 1.013) with median values of (x = 14.67, y = 15.10, z = 34.31) that yields a

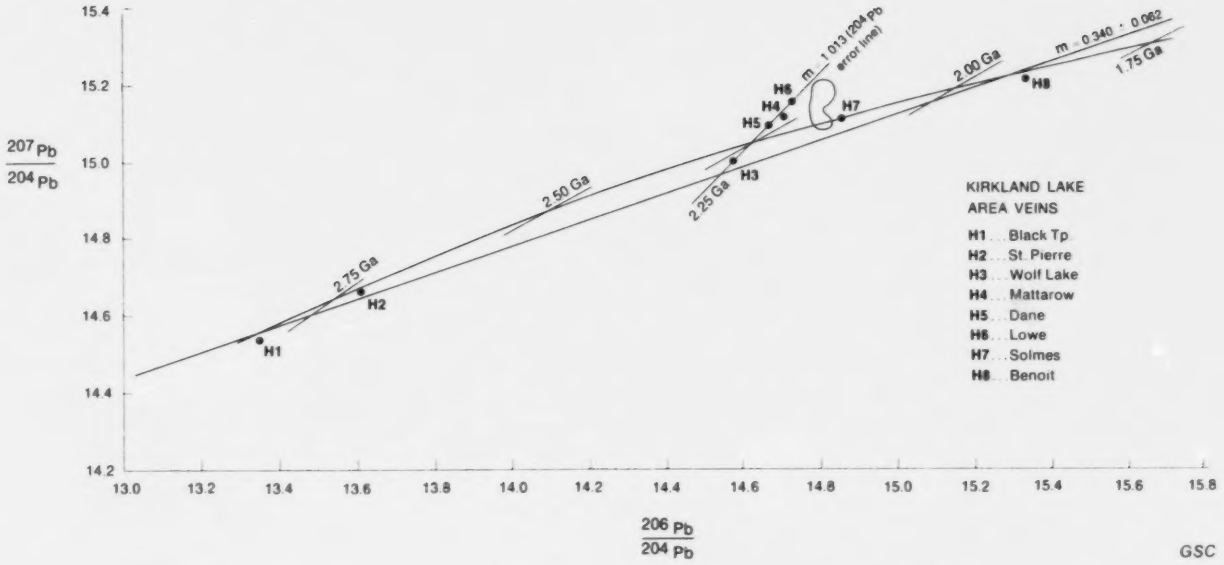

Figure 15. *Isotopic composition of galena samples from veins in the Kirkland Lake area.*

Note that samples H3 to H6 are distributed along an error line. The regression line (m = 0.340) is calculated excluding points H4 to H6. Circled area is the compositional range of Cobalt vein galena samples.

single stage age of 2280 Ma. These samples were formed in a relatively high U/Pb environment (μ = 10.0) compared with massive sulphide deposits.

The Dane, Mattarrow and Lowe samples are compositionally similar to the Cobalt vein samples (Appendix, Table A.5), although they are shifted to a slightly lower $^{206}Pb/^{204}Pb$ position. These occurrences have a homogeneous lead isotope composition; such homogeneity in scattered vein occurrences may be the result of a moderately intense thermal or hydrothermal event, such as might be related to intrusive activity. The high μ composition may indicate a local crustal source for most of the lead. Thorpe and Kirkham (1972) noted a similar homogeneous composition for a group of widespread vein deposits in the Smithers, British Columbia area, and relate the genesis of the galena samples to magmatism. Possible post-volcanic magmatic events in the Kirkland lake area are: (i) alkalic intrusive rocks, present near Matarrow, Dane (Lebel stock), Lowe (McElroy stock), and Wolf Lake (alkalic dykes, R.H. Ridler, personal communication, 1975), and (ii) the Nipissing diabase sill, remnants of which are present throughout the region.

The compositional similarity of these galena samples to the galena samples from the Cobalt veins (see Appendix, Table A.5), and the median model age of 2280 Ma are both compatible with the Nipissing diabase intrusive event (2120 Ma). The alkalic intrusions have a minimum age of 2600 Ma (Otto stock, R.K. Wanless, personal communication, 1979), which is less compatible with the model age for our samples.

The five samples which form a secondary isochron (Black Tp., St. Pierre, Wolf Lake, Solmes and Benoit) also give some information regarding the vein-forming event.

Galena samples from the Black Township and St. Pierre occurrences have lead-isotopic compositions which lie near the top of the massive sulphide cluster (trend 'a', Fig. 7, p. 14). These veins may have formed penecontemporaneously with their Archean volcanic rocks, or may have had only minor additions of radiogenic lead. The secondary isochron has a slope of 0.340. It intersects the massive sulphide cluster towards its top, and as the two aforementioned samples lie within or near this cluster, a t_r = 2700 ± 50 Ma age may reasonably be assumed. This yields t_s = 2080 ± 60 Ma which overlaps the age of the Nipissing diabase. Alternatively, assigning a remobilization age of 2120 Ma yields a source rock age of 2670 Ma. This secondary isochron can clearly be interpreted as the result of remobilization of lead from Archean volcanic and sedimentary source rocks by the thermal effect of the Nipissing diabase intrusions.

Tribag Deposit

This deposit is a breccia-pipe porphyry copper deposit, which cuts Archean rocks and a Keweenawan dyke. The ore is cut by another Keweenawan dyke, and the approximate age of ore formation has been established by two K/Ar age determinations, of 1055 ± 35 Ma and 830 ± 84 Ma on muscovite in the altered wall rocks (Wanless et al., 1967, sample GSC 65-106). The lead isotope analyses indicate an average model age of 1381 Ma and also indicate that the lead was generated in a high μ environment. This model age is somewhat older than the age range generally assigned to Keweenawan igneous activity (1050-1200 Ma). Calculation by the Cumming and Richards model, however, yields a model age of 1200 Ma, in closer agreement with the period of igneous activity. More recent, high quality data (Pearson, 1980) gives ages of 1375 Ma (Stacey-Kramers) and 1176 Ma (Cumming-Richards), confirming our data. The high μ and W of these samples indicates generation of lead in an environment enriched in U and Th, and its probable derivation from a crustal source such as the adjacent granitic rocks. Further data are required in order to accurately evaluate the lead-isotopic genesis.

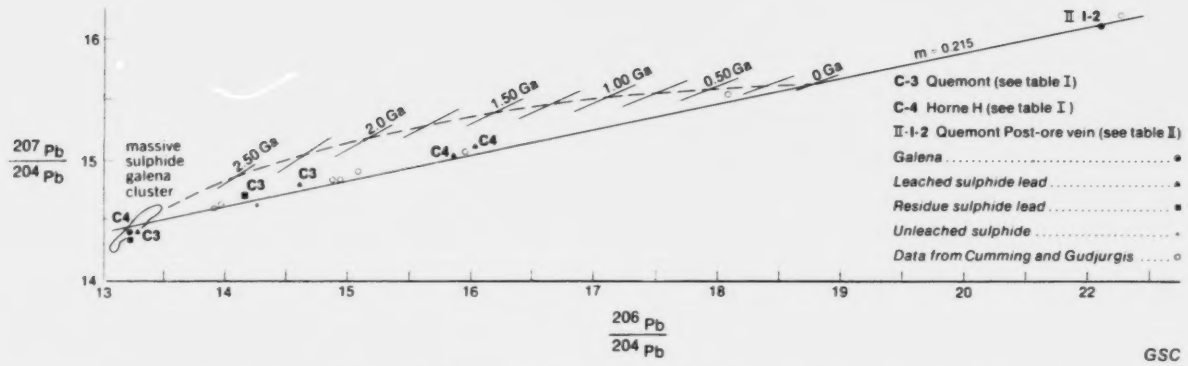

Figure 16. *Isotopic compositions of galena and non-lead sulphides, Quemont Mine and Horne H Mine.*

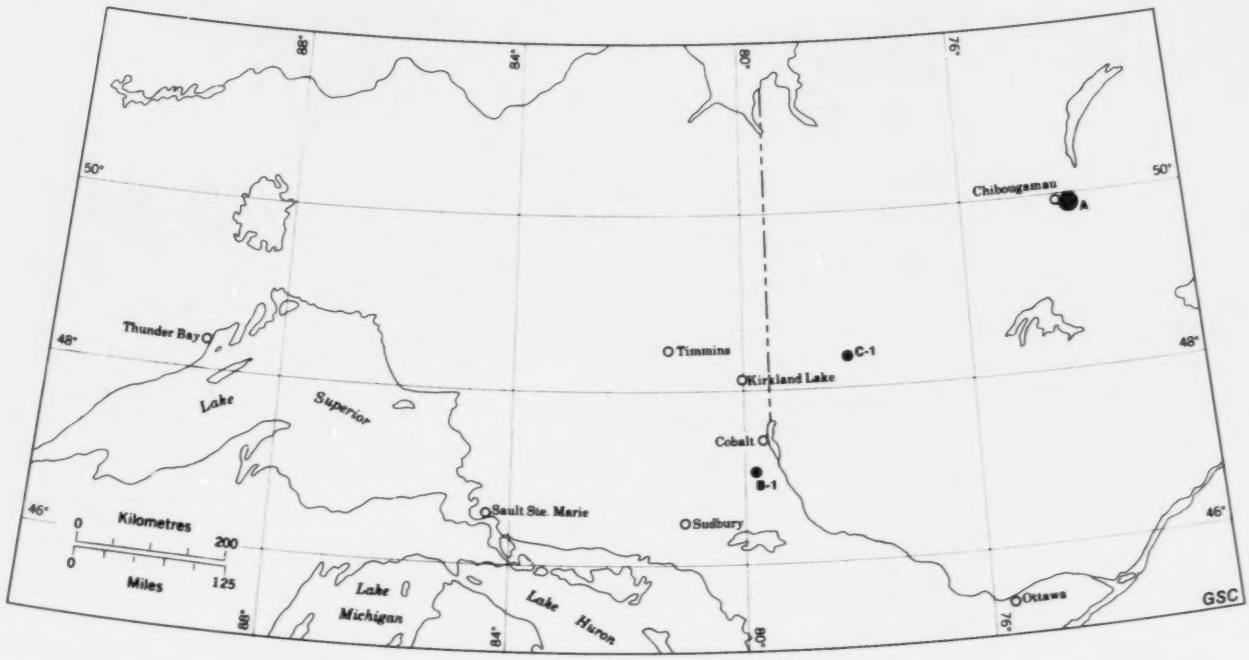

Figure 17. *Group III deposit locations; sulphide deposits associated with Archean ultramafic and anorthositic rocks.*

Other Veins

The model age of the Joannes Township vein is 2497 Ma (μ = 10.09). This age is fairly consistent with the age of regional metamorphism (Kenoran Orogeny) of approximately 2600 Ma. The relatively high μ, compared with the massive sulphide cluster, the age and textural evidence all suggest that the lead was formed by local remobilization out of adjacent country rocks during the Kenoran Orogeny.

The Quemont vein galena is clearly anomalous. A similar composition of Quemont vein galena is recorded by Cumming and Gudjurgis (1973). If both galena compositions are compared with all available trace lead isotopic data (this report, and Cumming and Gudjurgis, 1973) a total of 15 analyses are available, which form a very distinct secondary isochron (Fig. 16). Our leach-residue data (samples 65RF048 and 65RF049, Appendix, Table A.1, deposit C3, ibid.) indicate a variable composition of both leach and residue components, and thus additions of variable amounts of radiogenic lead, the latter having grown in variable μ environments. Together with the galena data, these data are suitable for two-stage interpretation. The slope of the secondary isochron is R = 0.215, very similar to that obtained by Cumming and Gudjurgis (1973). The Horne H leached-lead compositions also lie on this line (Appendix, Table A.1, deposit C4). As the Quemont deposit is one of a group of Noranda area volcanogenic massive sulphide deposits (Weeks, 1967; Taylor, 1957), it is probable that the initial sulphide deposition occurred contemporaneously with the other deposits and the enclosing volcanic strata, at approximately 2710 Ma. Model ages on the pyrrhotite and pyrite residues yield ages of 2643 Ma and 2135 Ma, respectively, indicating that these sulphides are at least that old. Assuming initial homogenization (t_r) at 2710 Ma, the radiogenic component (t_s) would have been added at approximately 600 Ma. An early Paleozoic event appears to have affected the ores of the Horne-Quemont

area; this event is recorded only by minor radiogenic addition to non-lead sulphides and by vein galena. Although there is no clear evidence of Paleozoic tectonic activity in the Noranda area, fault movements and magmatism evident near Virginiatown (40 km to the west) attest to Phanerozoic events which may have included ore recrystallization at Quemont. Both Weeks (1967) and Taylor (1957) described ore textures which are typical of such intense recrystallization.

The Fabre Township and Pays Plat analyses are also clearly anomalous, but without additional data, are uninterpretable.

Group III: Sulphide Deposits Associated With Ultramafic and Anorthositic Intrusive Rocks in Archean Terrane

A variety of deposit types are represented by this group. The deposit locations are illustrated in Figure 17, and each major type is described below.

(a) Chibougamau type

Copper deposits in the Chibougamau area form a distinct, yet poorly understood class with the following characteristics:

i) Chalcopyrite forms the principal ore mineral, and occurs with siderite, pyrite, pyrrhotite, and minor sphalerite. Molybdenite and scheelite occur in some deposits. Gold is recovered from most deposits.

ii) Chalcopyrite forms vein networks.

iii) The veins are contained entirely within gabbro, anorthositic gabbro and anorthosite. Much of the ore lies near or along dykes (Duquette, 1970) which are probably derived from the Chibougamau Lake pluton.

iv) The wall rocks show variable degrees of hydrothermal alteration, accompanied by K_2O, SiO_2, CO_2 and H_2O additions.

The alteration is localized in extent at the Opemiska mine, but pervasive at Campbell Chibougamau. Duquette (1970) indicated that the metals in all deposits of this group are derived from the Chibougamau Lake and Opemiska granodioritic plutons, whereas McMillan (1972) suggested a subvolcanic origin for the Opemiska deposit. Allard (1976) suggested a subvolcanic origin for all Cu-Au deposits; he considers the Patino deposit in Lemoine Township to be a synvolcanic exhalative massive sulphide deposit.

(b) Nickel Deposits

The two occurrences included in the class have two common factors:

i) nickel enrichment in a sulphide phase;

ii) sulphides occur within mafic or ultramafic intrusive rocks.

The O'Connor occurrence in the Timagami area is at the base of an extensive sill, and forms part of a sulphide zone which extends southwest to Timagami Island. Copper deposits elsewhere on the island are overlain by the same sill. The sulphides in the sill are interpreted as having separated by immiscible segregation from the sill but they have undergone subsequent alteration (Franklin, 1967; Robertson, 1977).

Although highly deformed, the Marbridge deposit (Val d'Or area) is probably typical of nickel deposits formed in Archean ultramafic bodies (Clark, 1965). The mechanism of formation ascribed to any of these deposits is complex, possibly involving such processes as immiscible segregation, sulphurization, and forceful injection of sulphide melt. The host rocks (commonly serpentinized peridotite) usually are ascribed to an intrusive origin (Naldrett, 1966) but may also be altered ultramafic flows (Pyke et al., 1973).

Interpretation, Sulphides Associated with Ultramafic and Anorthositic Rocks

Data for these deposits are given in the Appendix, Table A.3, and shown on Appendix, Figure A.3 (in pocket). These data were obtained primarily from low-lead sulphides. These have probably undergone some degree of 'geological contamination', thus obscuring direct interpretation regarding primary, depositional age of the deposits. Sufficient data from two groups of samples are, however, available to attempt some interpretation.

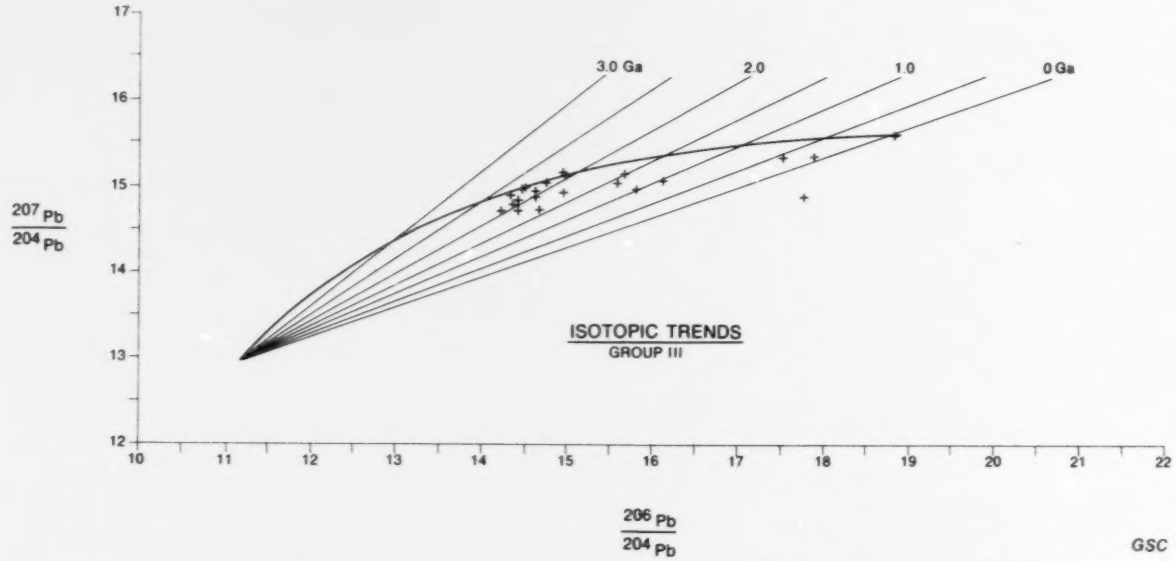

Figure 18. *Group III data distribution: sulphide deposits associated with Archean ultramafic and anorthositic rocks.*

Chibougamau Deposits

Lack of available galena from these deposits hampers a conventional interpretation of the isotope data. The leach-residue data clearly indicate an anomalous trend but definition of a single, well-defined anomalous line is difficult. The large amount of radiogenic lead added to the pyrite suggests a multiple stage history, with at least one episode of addition of radiogenic lead. The scatter of data may be the result of different lead-uranium ratios in source rocks of each deposit, or may be the result of episodic lead addition.

Combining the data from all of the Chibougamau deposits, an anomalous line of slope 0.190 ± .028 gives, by means of a conventional two-stage interpretation, a maximum age of 2740 Ma. This age is closely coincident with that of the massive sulphide cluster and the age of deposition of most Archean greenstone belts of the Superior Province. It represents the age of the oldest rocks which could have supplied the lead, and indicates that the lead in the Chibougamau deposits may have been derived by continuous addition of lead until present, or that the lead has been added and in part homogenized in a relatively recent event. The initial time of metal concentration may be Archean, consistent with Duquette's (1970) suggestion of a pre-Kenoran age of the gabbro bodies, and McMillan's (1972) suggestion of a synvolcanic age of ore emplacement.

The secondary isotopic component of these samples cannot be assigned simply to a continuous addition model, as samples of leached, unleached and residue lead, along with galena lead, are all interspersed along the secondary isochron. Possibly the lead was homogenized in one or more relatively recent (Phanerozoic?) events; uranium, although present at Opemiska in uraninite, is not likely incorporated in the sulphide minerals analyzed. The residue lead compositions are quite radiogenic (yielding young model ages), and thus pyrite at least may have been redeposited in recent times.

The intersection of the anomalous line with the 2700 Ma isochron is at a slightly higher μ than the centroid of the massive sulphide cluster (Table 6), indicating that the initial non-radiogenic component of the radiogenic lead was generated in a slightly higher U/Pb environment.

O'Connor Property

This deposit is composed of nickeliferous pyrite at the base of a 'metadiorite' sill. It is laterally equivalent, and genetically similar, to the pyritic zone of Temagami Copper Mines Ltd. Two genetic models have been proposed for the Temagami Copper occurrence. Franklin (1967) suggested direct segregation of immiscible sulphide solution as droplets from the metadiorite, to form a monosulphide solid solution body which subsequently, due to metamorphism, converted from a pyrrhotitic to pyritic assemblage. Colvine (1974) suggested incorporation of a pre-existing synvolcanic massive sulphide into the metadiorite sill to produce a laterally extensive pyrite zone. Neither model establishes the age of the sill and sulphides although Robertson (1977) noted the similar tholeiitic chemical composition of the sill and nearby mafic volcanic rocks, and suggested that the sill and volcanic rocks are comagmatic.

Analyses from the O'Connor property were undertaken as a second leach-residue experiment, on a deposit which may be genetically unrelated to the previously described Temagami Mine Road occurrence. Both deposits may have undergone a similar metamorphic history.

The systematics are comparable to those of the Temagami Mine Road pyrite in which the linear array of unleached sample analyses are the result of mixing in variable proportions of the older residue phase and younger leachable phase. However the systematics of the O'Connor pyrite are less well defined due to analytical problems with the low lead levels in the residue and, particularly, the leach component.

The attempted analyses of the leach lead from the first leach-residue pair was unsuccessful due to the insufficient quantity of the lead; for this reason we have no information on the homogeneity of the isotopic composition of the leachable lead. The quality of the residue lead and unleached lead analyses may also have been poor due to the low lead levels, contributing to the observed deviation of the unleached analysis from the mixing line defined by the leach and residue leads. The average of the results of two analyses on the residue lead yields a model age of 2292 Ma (μ = 9.35) and the single leach result gives a model age of 941 Ma and a lower μ of 8.1. The μ value for the residue lead is comparable with that of both the leach and residue leads from the Temagami Mine Road pyrite (61RF0388, Appendix, Table A.2) indicating that the two pyrite samples may have been generated by the same source rocks but at different times. If this is the case, the model age may be a valid indication of the age of deposition of the pyrite.

The model age of the average residue composition is close to the model age of the galena 'cluster' of the Cobalt silver veins (2280 Ma, recalculated from Thorpe's (1974) data). Galena in the silver veins probably formed due to precipitation from a homogeneous solution generated by the thermal effects of the Nipissing diabase. The latter diabase is present near the O'Connor Sill; the residue component of the O'Connor sample may have been formed by recrystallization of the pyrite due to similar thermal effects by the Nipissing sill.

The lower μ value of 8.1 for the single leach analysis indicates that the leach lead was not formed through the continuing accumulation of radiogenic lead in the source rocks of the residue lead. A more complex explanation is required which is not attempted here due to the lack of information about the homogeneity of the composition of the leach lead, and the doubtful quality of the analytical results associated with these low lead samples.

The similarities between the O'Connor pyrite and the Temagami Mine Road occurrence are in the systematics. Leads from both pyrites may be separated into two phases; an older phase intimately associated with the pyrite itself, and a younger phase surficial to the pyrite. The differences are in the model ages of the two phases; 2707 and 1670 Ma for the Temagami pyrite and 2292 and 941 Ma for the O'Connor. The μ value for the residue phase of the O'Connor pyrite is comparable with the μ for both phases of the Temagami pyrite sample, indicating a possible genetic link. The μ value for the surficial phase of the O'Connor pyrite is much lower.

Under certain assumptions it may be possible to treat the slope of the line joining the residue and leachable phases as that of a secondary isochron. This slope for the Temagami Mine Road pyrite is 0.293 ± 0.043; for the O'Connor pyrite, 0.108 ± 0.090. The considerably different slopes are probably indicative of different histories for the radiogenic components of the two surficial leads.

Marbridge

The single value from Marbridge yields a model age of 2130 Ma. Interpretation of this is impossible, as this may be part of an anomalous suite, or may be part of a metamorphically updated population.

Group IV: Gold Deposits in Archean Rocks

Gold in Archean rocks is generally recognized as occurring in two broadly defined lithologic affinities; many of the important producers are clearly contained within Archean supracrustal strata, yet an equally large group of economically important deposits are within or near Archean intrusive rocks. Locations of the deposits described herein are shown in Figures 19 and 20.

(a) **Gold Deposits in Archean Volcanic and Sedimentary Strata**

Although deposits of this type occur in a wide variety of both volcanic and sedimentary rocks, the majority are found in relatively few environments. Typically, as in the Rouyn-Cadillac deposits (e.g. New Rouyn Merger), they are enclosed in sedimentary strata near the contact with underlying volcanic rocks. This 'contact' area commonly is associated with regional shear or fault zones, such as the Destor Porcupine or Cadillac-Malartic 'breaks'. The existence and significance of these 'breaks' has been scrutinized and their genetic relationship to gold deposits has been questioned (Ridler, 1970). In the Timmins area, most of the gold veins occur in volcanic strata, and immediately adjacent conglomerate.

Many deposits of this group occur in or near exhalite (Ridler and Shilts, 1974), particularly the carbonate facies of iron formation. While the spatial relationship of gold to 'proximal' volcanogenic iron formation is obvious for many deposits, a similar spatial relationship of gold deposits to ultramafic flows and related(?) alteration products has been noted in the Kerr Addison area. In the Timmins area, deposits such as Delnite and Paymaster are within or near carbonate and sulphide-rich strata, and could be considered as occurring in part in a 'carbonate facies' or 'sulphide facies' exhalative rock. Much of the carbonate may be an alteration of volcanic and sedimentary strata, however. The Dome and Broulan Reef deposits occur at least partially in coarse clastic, volcanic-derived sedimentary rocks, and adjacent volcanic strata.

A few deposits occur totally within volcanic strata. Some are within mafic and ultramafic rocks, others are in felsic volcanic and subvolcanic units, typically quartz-feldspar porphyry (e.g. Smith Thorne). Interpretation of quartz-feldspar porphyry bodies as being an extrusive volcanic product is tenuous in many areas, and some deposits in this environment might better be placed in the class associated with intrusive rocks, described below.

(b) **Gold Deposits Associated with Intrusive Rocks**

The second distinct type of gold deposits comprises those associated with intrusive bodies. The majority occur as vein networks which form a halo around the outer margins of salic bodies such as granite, syenite, tonalite, granodiorite, quartz monzonite and diorite. Some are associated with 'quartz-feldspar porphyry' bodies, which are probably subvolcanic (high-level intrusive) in origin, whereas others, particularly in the Kirkland Lake and Malartic-Val d'Or areas, are associated with alkalic syenite bodies. The veins extend into the adjacent country rocks and contain native gold, electrum, tellurides, and sulphides. Most of these intrusive bodies are a few thousand metres in diameter, circular or ovoid in plan, and all are intrusive into Archean supracrustal strata. All occur near a major transition from volcanic (dominantly mafic) to sedimentary rocks.

Several of these intrusive bodies have copper enrichment zones in the central core and bear a remarkable resemblance to porphyry copper(-molybdenum) deposits (e.g. McIntyre), as pointed out by Kirkham and Thorpe (1973).

Interpretation, Gold Deposits

Data for these deposits are given in Appendix, Table A.4, and plotted on Appendix, Figure A.4 (in pocket). These analyses may be resolved into two general trends, 'e' and 'f', on Figure 21. Because gold in the stratabound deposits probably has a different genetic history than gold in intrusive rocks, analyses from the two groups will be discussed separately, and the selected data for each are shown in Figures 22 and 23.

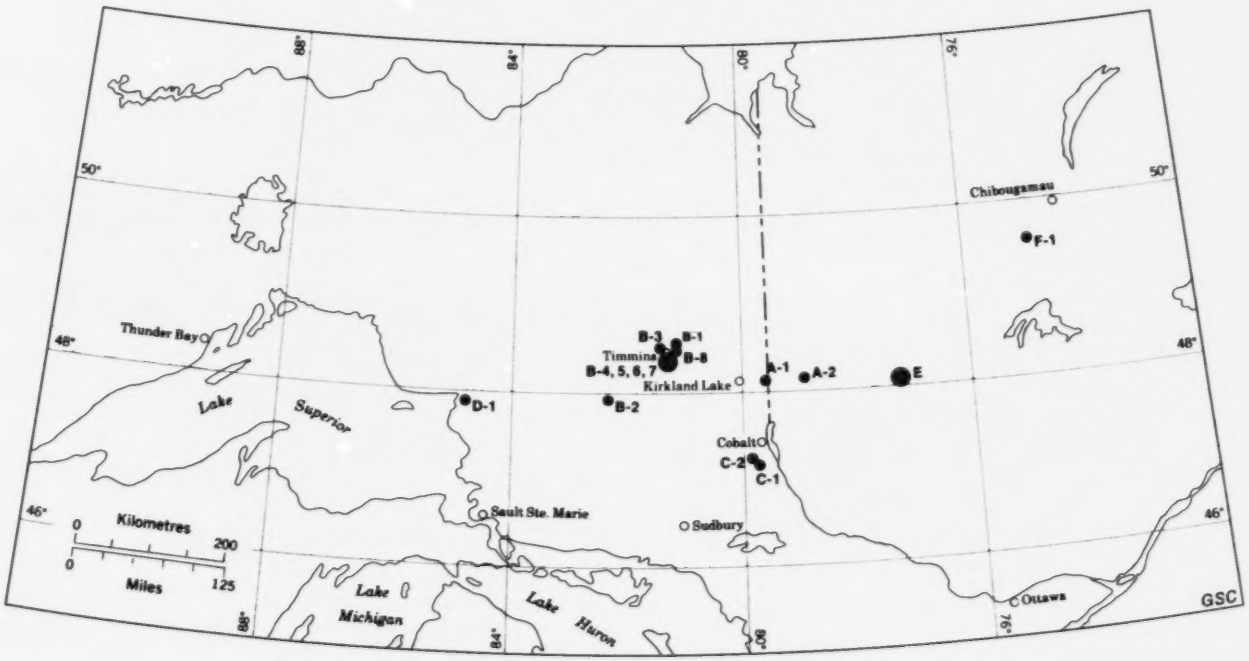

Figure 19. *Group IVa deposit locations; Archean stratabound gold deposits.*

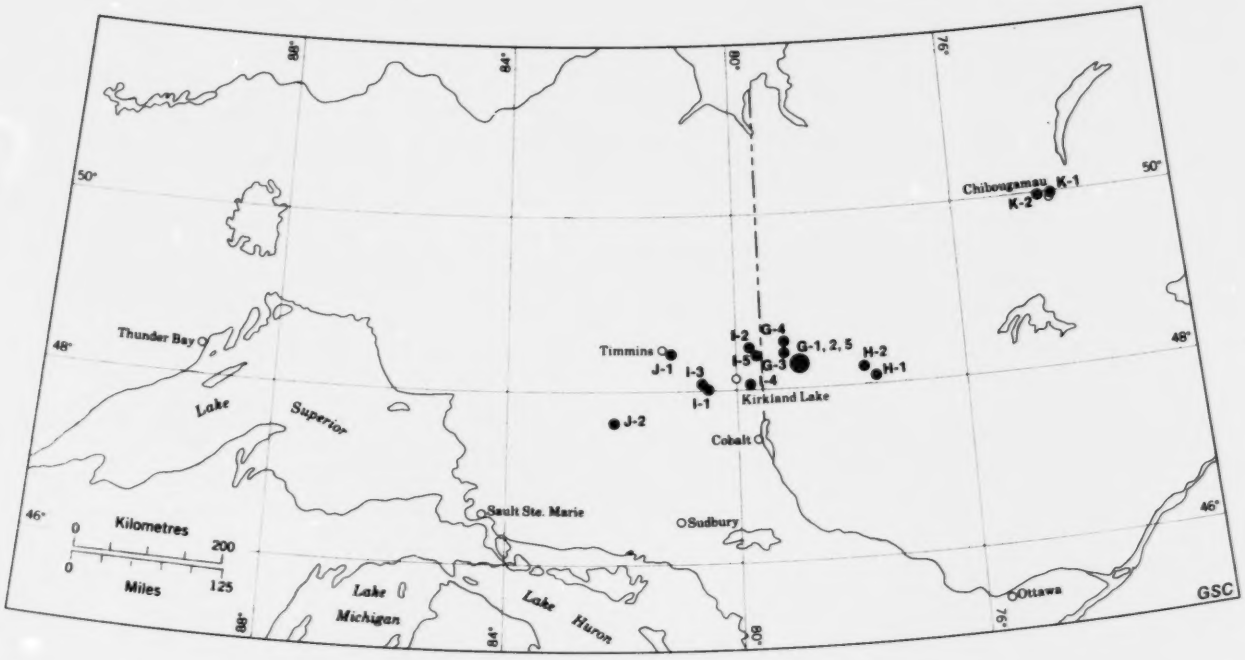

Figure 20. *Group IVb deposit locations; Archean intrusion-related gold deposits.*

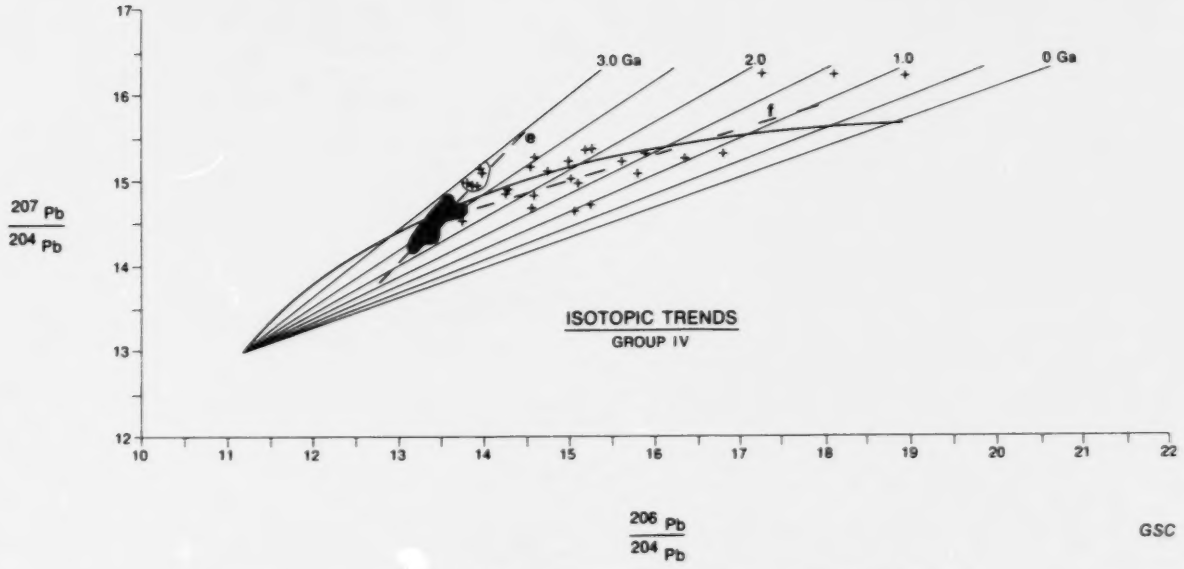

Figure 21. *Group IV major isotopic clusters and trends; Archean gold deposits.*

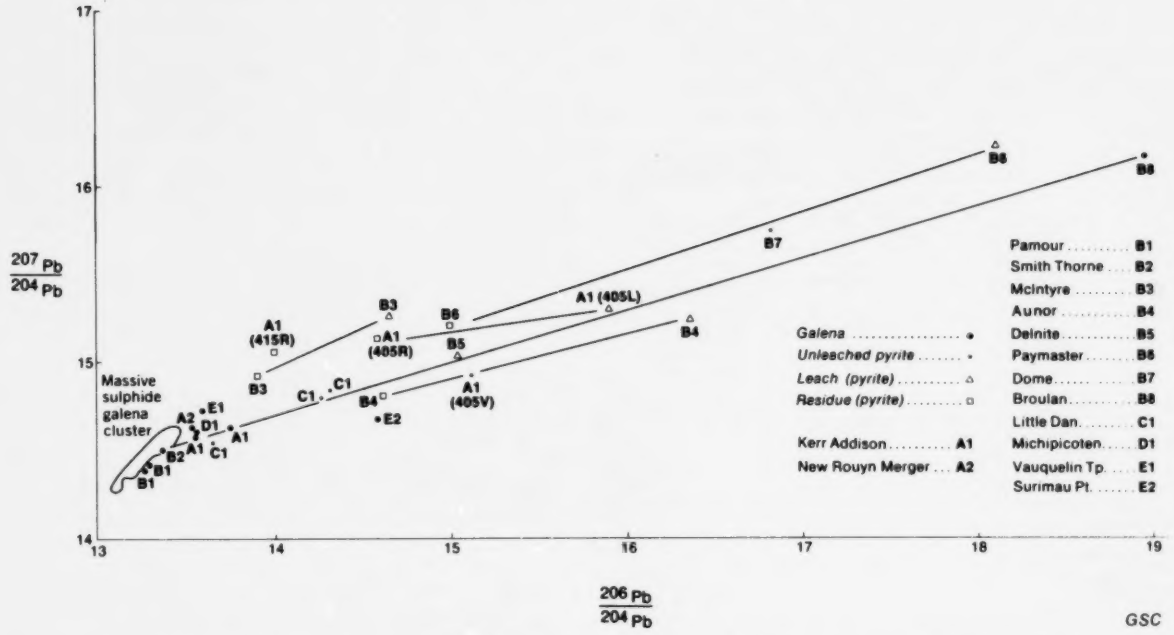

Figure 22. *Secondary isochrons derived principally from leach-residue studies of non-galena samples, Archean stratabound gold deposits.*

Gold in Stratabound Deposits (Fig. 22)

(a) All galena samples except those from Kerr Addison, Hermiston-McCauley and Broulan Reef lie in trend 'e' (Fig. 21), lie within or near the massive sulphide cluster (Fig. 6, trend 'a'), and form a cluster along an error line. The centroid of this group is at x = 13.48, y = 14.55, z = 33.23, which gives a single stage age of 2635 Ma (μ = 8.61). This composition is slightly more radiogenic than the centroid for the lead isotope compositions of the massive sulphide deposits (Table 6) and the age is somewhat younger. The U/Pb ratio of the environment which supplied the radiogenic lead is obviously slightly higher than that of the environment of lead generation for the massive sulphide cluster and may indicate a larger amount of crustal 'contamination' of the lead during the formational processes associated with gold-vein deposition.

The two Kerr Addison galena samples and the Broulan Reef galena sample form a secondary isochron as part of trend 'f' (Fig. 21) with a slope of R = 0.30. This is a similar slope to that observed for several of the pyrite leach-residue pairs, and is discussed below.

(b) The analyses of pyrite indicate a general anomalous character of the lead in all deposits tested. The data form part of trend 'f' but are scattered and do not permit construction of a single statistically sound regression line. The data all lie in a high μ region indicating generation of lead in a uranium-rich environment, relative to either the galena samples of this class of deposits or the galena samples of the massive sulphide cluster.

Examination of the various leach-residue pairs indicates that in all cases the easily leachable lead is distinctly more radiogenic than the residue component. Although each pair forms a line with poor statistical significance, comparison of the slopes of the various secondary isochrons (Table 6) indicates two, and possibly three, groupings with slopes of (i) 0.45 to 0.49, (ii) 0.25 to 0.32. and (iii) 0.11. The first two slopes are also present in the next group of deposits (gold related to intrusive rocks) and will be discussed later. The third slope is formed from a Kerr Addison leach-residue pair; samples 415 (R and L) and 405 (unleached) do not fall on this line; thus the line is probably not significant.

Gold in Intrusive Rocks (Fig. 23)

(a) Galena analyses form three distinct groups which together constitute part of the 'f' trend. The most isotopically primitive group (Flavelle Township, Sullivan) lie in the 2750-2640 Ma cluster (trend 'e') and have a slightly younger model age than the massive sulphide group. These deposits may have formed penecontemporaneously with either volcanism or the temporally related intrusive activity; alternatively they may have formed at the onset of the Kenoran Orogeny.

The second group (Buffonto, Alma Township, and Upper Canada) lie on an error line near the 2400 Ma isochron. These deposits appear to have formed as a consequence of some late Archean event, such as the emplacement of the alkalic syenites (approximately 2600 Ma, R.K. Wanless, personal communication, 1979), or the Kenoran Orogeny. It is noteworthy that all of the deposits of this group are spatially associated with K-rich or alkalic syenite bodies.

The third group include the Harker and Jerome deposits. The latter deposits contain galena which appears to have young model ages (approximately 2150 Ma). Both deposits are cut by post-Archean diabase dykes, and at Harker remobilization of the gold by this dyke has been noted (Gledhill, 1925). Although the high μ and young model age may indicate that these isotopic compositions are anomalous, it is interesting to note that the ages are close to that of the Nipissing diabase (2116 ± 27 Ma. Fairbairn et al., 1969), and remobilization may have taken place at that time. Nipissing diabase sills occur in the vicinity of both of these deposits. The Harker and Jerome galena samples form a secondary isochron (R = 0.45) which passes through the Alma-Buffonto-Upper Canada cluster, and extends back to the Sullivan and

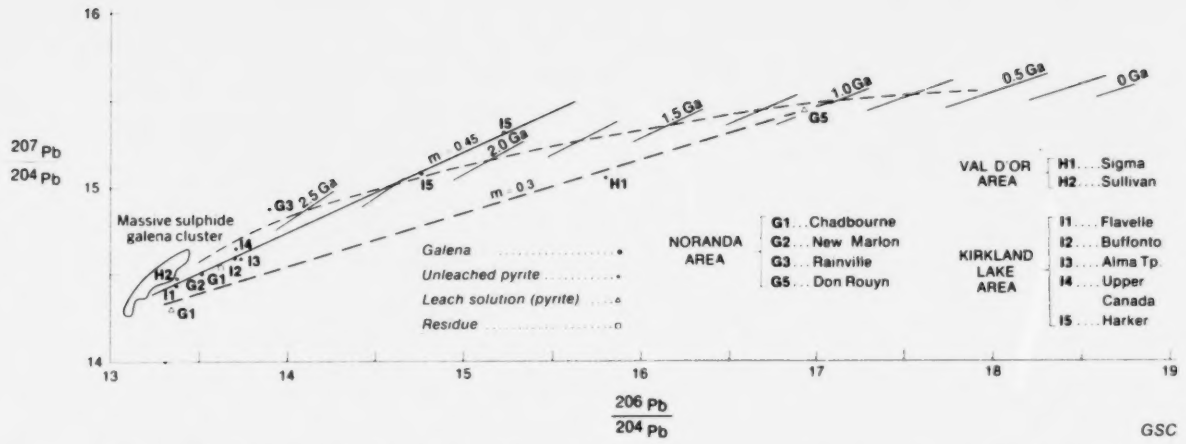

Figure 23. *Secondary isochrons derived from both galena samples and leach-residue studies of non-galena samples, Archean intrusion-related gold deposits.*

Flavelle Township samples. All of these samples are galena, and thus a significant amount of radiogenic lead is necessary in order to cause their anomalous compositions.

(b) Trace lead in pyrite from these deposits generally has an anomalous composition. Data from Chadbourne (one analysis), Sigma and Don Rouyn form a secondary isochron with slope R = 0.22. The secondary isochron slope is similar to that of many of the leach-residue pairs and galena samples from the stratiform deposits, and will be considered in the context of the latter group.

Summary Interpretation of Secondary Isochrons

The slopes of secondary isochrons are summarized in Table 7. The two isochrons formed by the galena samples (0.30 and 0.45) are most significant due to the large sample population, small error levels, and the relatively large (and therefore significant) amount of radiogenic lead added to make the anomalous compositions.

Both trends must be analyzed in view of the approximately 2700 Ma age of the Abitibi belt (which hosts the deposits). Clearly, from the non-anomalous galena samples described above, portions of the Pamour, Smith Thorne, Kerr Addison, Sullivan, Flavelle Township, and Rainville deposits were formed at this time. From the pyrite and galena data, a Kenoran (2600 ± 50 Ma) event has affected the isotopic composition of Upper Canada, Buffonto, Alma Township, Chadbourne, New Marlon, New Rouyn Merger, Michipicoten, Vauquelin and Little Dan deposits. All of the deposits in this study show the effects of Kenoran deformation, and thus this orogeny represents a second important 'time' in the deposit histories.

The R = 0.45 lines are important in that either they were generated instantaneously at 2700 Ma in a high μ (very uranium-rich) environment, or the starting time of the lead evolutionary system (t_r) is older than 2700 Ma, the host rock age.

Virtually all of the deposits (except Little Dan) which comprise this secondary isochron are related to syenite intrusions. These intrusions are not commonly deformed, and may in part be synorogenic or penecontemporaneous post-orogenic bodies, emplaced during the Kenoran Orogeny. The syenites are also notable for their high radio-element content (H. Lovell, personal communication, 1978). Thus a significant secondary radiogenic lead component could be generated easily from these syenites relative to generation of a similar component from Archean volcanic rocks. Although 'instantaneous' radiogenic addition is unlikely, a relatively short period of radiogenic lead generation could account for the secondary isochron. Selection of a geologically reasonable remobilization time is difficult as the times of syenite intrusion, and also of deformation, are unknown. However, if remobilization, and also possibly syenite emplacement, occurred during the Kenoran orogenic event (e.g. at approximately 2550 Ma) then the uranium which generated this radiogenic lead component was placed in the crust at approximately 2930 Ma. As the host rocks are probably much younger (i.e. 2750 to 2500 Ma), the 2930 Ma date must represent the time of formation of the source 'system' from which was generated either or both the

Table 7. Slopes of secondary isochrons, including pyrite samples (unleached and leach-residue (L-R) pairs) from gold deposits associated with intrusive and stratiform rocks (Groups IVa and IVb)

Deposit or Group of Deposits	Slope	1σ error	No. of Samples
Galena associated with stratiform deposits	0.30	0.02	8
Aunor (L-R)	0.25	0.07	2
Paymaster (L-R)	0.32	0.04	2
Little Dan (L-R)	0.45	0.13	3
Don Rouyn-Sigma-Chadbourne (L-R)-New Marlon	0.22	0.05	4
Galena associated with intrusion-hosted deposits	0.45	0.03	8
McIntyre (L-R)	0.11	0.09	2

2700 Ma and 2500 Ma radiogenic components. The 2930 Ma age may thus be that of the source rocks which melted to form the syenite intrusions and also possibly the volcanic strata.

The mechanism which generated the R = 0.30 lines is much more obscure. A two stage system adding radiogenic lead to lead generated at 2700 ± 50 Ma would require a remobilization event at approximately 1700 Ma. In view of the widespread areal distribution of the deposits which display secondary isochrons of this slope, the probability of a Penokean or Hudsonian orogenic effect on these deposits may be small; however, Card et al. (1972) considered all of the terrane covered by Huronian strata to have been mildly affected by the Penokean Orogeny. Thus the gold deposits of the Timmins, Kirkland Lake, and Noranda areas may have been similarly affected. The Sigma lead isotopic composition is not as easily explainable by this mechanism, however, as this deposit is located 50 km east of preserved Huronian strata.

As an alternate explanation a multistage model may explain the R = 0.30 slope. The secondary isochron may be the result of several radiogenic additions between 2700 ± 50 Ma (host rock age) and the present. As the principal events which might have affected the areas of these deposits are the Kenoran Orogeny and possibly the Nipissing diabase, it is important to test these events by way of the two stage equation (5). Assuming t_r = 2500 ± 50 Ma, indicating the homogenization of uranium and lead during the Kenoran 'Orogeny', the t_s time is approximately 2000 ± 70 Ma; given the statistical variations in the secondary isochron slopes, it is entirely possible that t_s represents secondary lead addition due to Nipissing diabase metamorphism. The homogeneous (t_r = 2500 Ma) component was generated during the Kenoran 'Orogeny', probably by accumulation of radiogenic lead and common lead from adjacent volcanic strata into gold-bearing veins. This lead thus came from strata of approximately 2700 Ma depositional age. Both the 2500 Ma and 2700 Ma events are recorded in the isotopic data as clusters of data which yield these model ages. Of the 43 analyzed samples 21% have model ages of 2740 ± 80 Ma, 30% have model ages of 2510 ± 57 Ma, 19% have model ages of 2212 ± 51 Ma and the remaining 30% have anomalous compositions with meaningless model ages. Thus the Archean depositional and Kenoran metamorphic events are clearly evident in the model age data. Furthermore, the Nipissing diabase event may be recorded, in addition to the R = 0.30 isochrons, by a cluster of model ages at 2212 ± 51 Ma.

Group V: Mineral Deposits in Aphebian and Helikian Rocks

Samples included in this group represent a wide range of types of deposits and sulphide occurrences. The deposit locations are shown in Figure 24, and are described below.

(a) Silver-Cobalt-Nickel Vein Deposits

All of these deposits are in the Cobalt-Gowganda area, and form a silver and nickel-cobalt sulpharsenide metallogenic subprovince. Silver, in association with nickel-cobalt arsenides and sulpharsenides, chalcopyrite, pyrite, galena, sphalerite and other sulphides, occurs in quartz-calcite veins which in some deposits cut Aphebian gabbro (Nipissing diabase), and in others cut Aphebian sedimentary rocks (Cobalt Group). These veins in some deposits also cut Archean rocks (dominantly supracrustal varieties). These veins have been well described by Boyle (1968), and by a series of authors in a Mineralogical Association of Canada Special Paper on the deposits of the Cobalt-Gowganda region (Petruk, 1971).

(b) Vein Deposits in Aphebian Sedimentary Rocks

The single gold-bearing occurrence near Kirkland Lake (Kenogami) examined in this study differs from the above group in that it does not contain the distinctive Cobalt-type mineral assemblage. The Mistassini area occurrences are

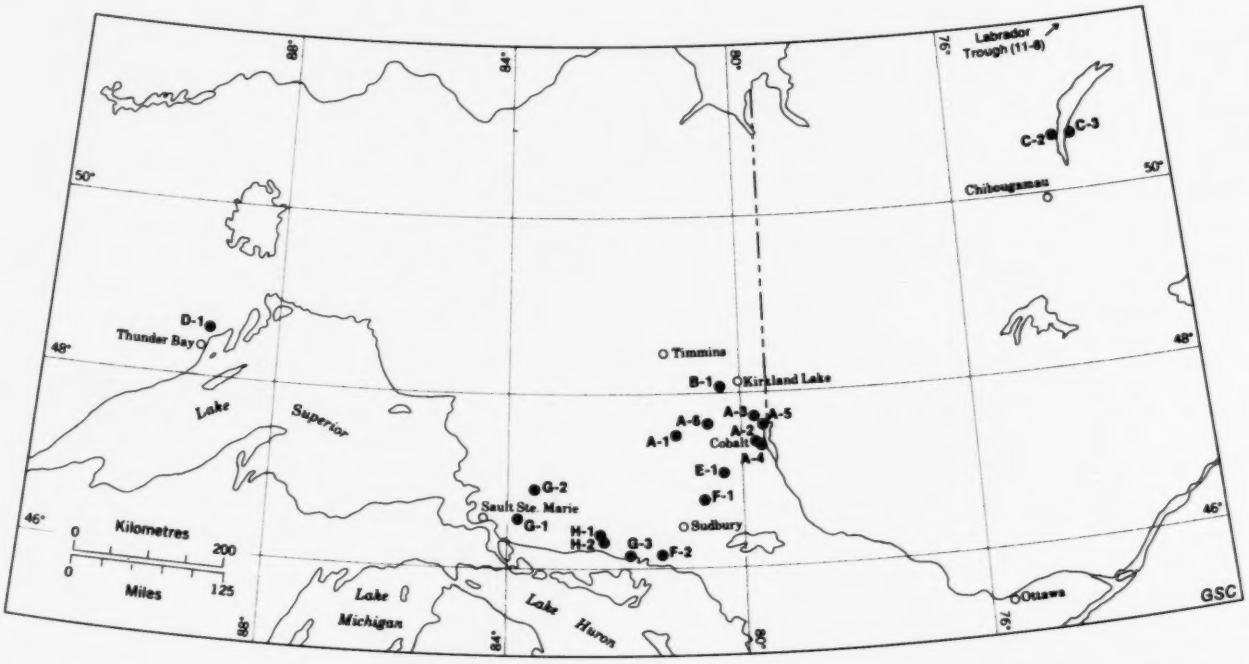

Figure 24. *Group V deposit locations; sulphide-bearing deposits in Aphebian rocks.*

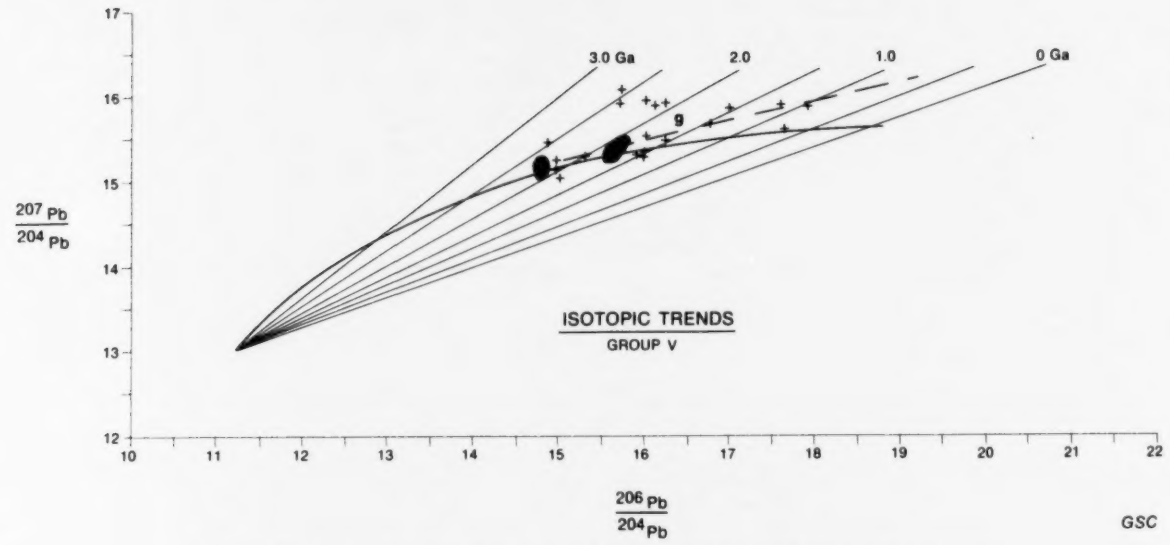

Figure 25. *Group V major clusters and trends; Aphebian sulphide-bearing deposits.*

zinc-lead (Mississippi Valley type?) veins in carbonate beds of the Mistassini Group. The Labrador Trough occurrences include both veins in gabbro and stratiform bodies.

(c) **Vein Deposits Associated with Gabbro and Gabbro-Sedimentary Contacts**

A variety of deposits have been included for convenience within this class. Most deposits are within Aphebian gabbro (generally Nipissing diabase) and a few are within Aphebian sedimentary rocks, but located near the contact with Aphebian gabbro. These deposits have probably been formed by a variety of genetic processes, including a possible contact metasomatic origin (e.g. Rangers Lake), lateral secretion origin (Shuniah silver vein) and magmatic segregation (Mongowin nickel-copper deposit). Little detailed study of most of the deposits has been completed, and detailed genetic interpretation and classification is not warranted.

(d) **Aphebian Disseminated Sulphides in Sedimentary Strata**

Two occurrences of disseminated sulphides in strata of the Elliot Group were sampled. The sulphides probably were deposited syngenetically as framboids and sulphide granules, but may have undergone subsequent metamorphism and recrystallization.

Interpretation of Isotopic Data for Aphebian Deposits

Data from these deposits fall into several discrete groups (Fig. 25) each of which may represent separate genetic modes. The data are given in Appendix, Table A.5, and plotted on Appendix, Figure A.5 (in pocket).

(a) **Cobalt deposits**

The data presented in this study generally confirm the observations of Thorpe (1974) although use of a new isotopic model changes the calculated ages slightly. Thorpe's cluster of galena compositions near his 2280 Ma isochron has a mean composition (x = 14.88, y = 15.13) which yields a new model age (Stacey and Kramers model) of 2248 Ma (μ = 10.10). A similar cluster of data (7 samples) reported herein has a mean value (x = 14.86, y = 15.16, z = 34.46) which yields a model age of 2215 Ma (μ = 10.14). The difference between the two values is statistically insignificant. The age is reasonably close to the age of the Nipissing diabase (2116 ± 27 Ma, Fairbairn et al., 1969).

Two samples (Langis and Miller Lake Basin mines) have anomalous values which form part of trend 'g' on Figure 25. The Lorrain vein (deposit J-2, Appendix, Table A.2) is a Cobalt-type silver vein, and galena from it is also anomalous. The anomalous or secondary isochron developed from these samples leads away from the cluster of 'common-lead' samples at 2215 Ma, and has a slope of 0.129 ± .031. Conventional two-stage interpretation of the data indicates a continuous addition age (t_s = 0) of 2085 Ma. Thus the source rocks which supplied the lead must not have been older than 2085 Ma. This age is close to the single-stage age of the main cluster of silver vein data, and suggests that the anomalous samples could have formed by continuous addition of radiogenic lead to 'common' lead, but no radioactive minerals have been identified in the veins. As an alternate explanation, the radiogenic component may have been added during the Phanerozoic, and the galena may have formed at that time. Post-Ordovician faulting in the Lake Temiskaming basin is obvious, and lead remobilization into these faults may account for the anomalous galena suite.

(b) **New Delhi Deposit**

These data conform closely to those reported by Kanasewich and Farquhar (1965) and represent spread along an error line. The mean value yields a single-stage model age of 1809^{+101}_{-110} Ma (2σ error) (μ = 9.95). The lead isotope data are tightly clustered, indicating thorough homogenization of the isotopes. Thus the lead was either deposited or thoroughly homogenized at that time.

The Nipissing diabase host rock is significantly older than the model age of this deposit, and does not appear to have played a direct role in its genesis. Although a major dyke of the Sudbury swarm passes immediately adjacent to the deposit (Lawton, 1954), the age of this swarm is believed to be 1300 Ma (Fahrig et al., 1965) and thus is incompatible with the lead isotope model age of the deposit.

The region is cut by several 'dykes' of Sudbury breccia, two of which are close to the deposit. The age of these breccias is 1704 ± 194 Ma ($\lambda Rb = 1.42 \times 10^{-11} a^{-1}$, Hurst, 1975), and the Rb/Sr age of the Sudbury Irruptive has been fixed at either 1909 Ma (Gibbons and McNutt, 1975) or 1843 ± 136 Ma (Hurst and Farhat, 1977). Krogh and Davis (1974) have determined a U/Pb (zircon) age on the Sudbury norite of 1844 ± 2 Ma. Thus there is only a small difference between the model age of New Delhi and the Rb/Sr and U/Pb ages of the Sudbury Intrusion.

Thus, further examination of the relationship of the Sudbury breccia to this deposit, including the determination of the age of any alteration associated with the deposit, should be undertaken. The age of the nearby Sudbury dyke should also be determined as it may be more closely related to the Sudbury Irruptive event.

(c) Mistassini Area Deposits

These data form a good secondary isochron with slope R = 0.339 (Fig. 26). As the occurrences do not contain measurable uranium, continuous addition and 'instantaneous' models are not applicable.

Two stage analysis is constrained by the age of the source rocks which provided the lead. The Mistassini Group is underlain by Archean basement rocks (both supracrustal sequences and granitic rocks) and may also be underlain by the Chibougamau clastic sedimentary strata of Aphebian age. Archean source rocks of 2550 to 2750 Ma would yield a mineralization age of 2250 to 2100 Ma. The latter may indicate the minimum age of the Mistassini Group. The secondary isochron extends back through the main Superior Province 'cluster' indicating that addition of radiogenic lead to the average Superior Province lead would account for the secondary isochron, and thus confirm the two-stage calculations outlined above.

The data also yield some genetic information. The fact that the data are spread along a secondary isochron, rather than forming a 'cluster', indicates that the solutions responsible for metal transport contained relatively small amounts of metal, compared to the solutions involved in massive sulphide genesis, and also that deposition of metal was probably a slow process.

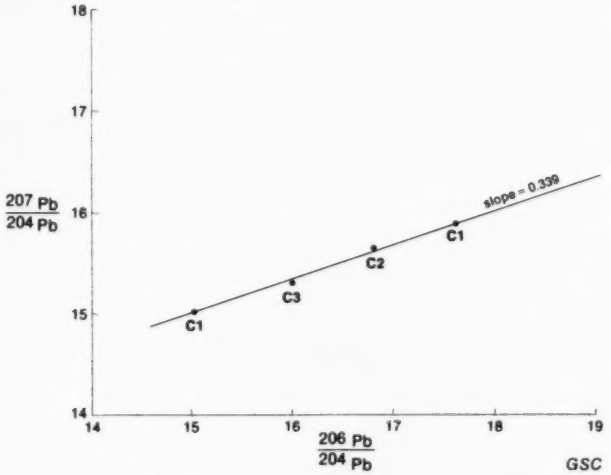

Figure 26. *Distribution of galena data, Mistassini area carbonate-hosted lead-zinc occurrences.*

(d) Labrador Trough Deposits

Samples from these deposits were donated to the Geological Survey, and are intended only as a test of the ages of various types of lead occurrences, and for information on the genetic processes involved in lead deposition. Most of the data plot well above the best-fit growth curve of Stacey and Kramers (1975) and have high apparent μ values (13.5 to 16.9); the model ages are suspect, as either the data are in error or the lead was homogenized in a secondary system.

The data are distributed on a poor secondary isochron of slope R = 0.34. This cannot be interpreted in the absence of additional age data on either the host strata or nearby gabbro bodies.

SUMMARY OF DATA

Analyses in this report yield both age and genetic information. Some of the more significant points are as follows:

(1) Model ages for galena from massive sulphide deposits are in general conformity with the age of the host rocks. Within individual camps, the galena compositions are essentially identical within the limits of error of the analyses of this study. These data are useful for comparing environments of lead formation between mining camps, and in addition differences between areas within the Shield. For example, the massive sulphide data in the Superior Province have a median μ value of 8.17, whereas similar data from Slave Province deposits have a much higher mean μ value with a much greater compositional spread (Thorpe, 1972). This may reflect differing crustal conditions between the two provinces, with uranium concentrated relative to lead in the Slave Province in comparison with the Superior Province, a fact consistent with the preliminary data presented by Fahrig and Eade (1971). This also may reflect a longer residence time of lead in U-bearing crustal rocks prior to separation and deposition in deposits in the Slave Province.

The difference in composition of galena between the Matagami and Noranda camps indicates a different environment of generation of lead for each camp. Noranda galena has isotopic ratios which indicate that the source rocks had a higher U/Pb ratio, and therefore were possibly more 'mature' than those which supplied lead to the Matagami deposits. Thus, calc-alkaline or felsic rocks may be the source of the Noranda lead, whereas at Matagami, mafic or less mature tholeiitic rocks of the ocean floor type might be the source.

(2) Data on the isotopic composition of low-lead sulphides, such as pyrite, are useful in further determining the depositional history, and also the metamorphic history, of the deposits. For example, the less radiogenic composition of the non-galena samples at both Noranda and Matagami requires further investigation. However, this isotopic difference between galena and non-galena species must result from somewhat different genetic histories. The general 'model' for massive sulphide deposits may require refinement to account for this difference.

(3) Important age and genetic information may be derived from precisely defined secondary isochrons. For example, if the time of metamorphism (t_S) is known and identical in several areas, the time of deposit emplacement (t_F) can then be calculated. Conversely, as wall rock ages and thus emplacement times of deposits become better established, then times of metamorphism can be more accurately determined. Archean 'metachrons' (secondary isochrons that were generated due to radiogenic addition at the time of metamorphism) with different (however slightly) slopes may indicate that times of emplacement or metamorphism differed from area to area, or even deposit to deposit.

Such studies would be most useful for volcanogenic massive sulphide deposits (Group 1). Some secondary isochrons cannot be interpreted as 'metachrons', due to their steep (~0.45) slopes. Further investigation of the Stralak and Kam Kotia deposits, with particular reference to ages of their host rocks, should be undertaken.

From the secondary isochrons examined in this study, several important aspects arise:

(a) late, and generally unsuspected, events appear to have caused remobilization of lead into veins (Quemont) or re-homogenization of lead due to metamorphism (Geneva Lake).

(b) an older crustal source for at least one major component of the lead can be seen at Stralak and perhaps at Kam Kotia. The validity of classifying the Stralak deposit as a massive sulphide deposit requires further investigation. Alternatively, the general model for massive sulphide genesis, which calls for a well mixed, metal rich brine to transport the metal, may require re-evaluation. The Kam Kotia deposit and nearby veins share a steep secondary isochron which results from the addition of a younger, relatively radiogenic component to an older lead component. The composition of the latter is generally similar to the common lead composition of the massive sulphide cluster, which may have been derived from an older, pre-volcanic source. Examination of the history of the host rocks might establish a 3.06 Ga precursor to them; such basement rocks might be present in the area.

(c) Gold deposits of the conformable stratiform class appear to have formed penecontemporaneously throughout the southern Superior Province, and are generally of the same age as, or slightly younger than, the massive sulphide deposits. The higher average μ value of galena from gold deposits relative to massive sulphides reflects some variation in their relative genetic modes, and may indicate some residence time of the lead in the crust before remobilization into its present form in the deposits. Alternatively, the lead may have originated in a different, more radiogenic (and more mature or older) part of the crust. The isotopic compositions of minor lead in pyrite, together with the galena compositions suggest a more complex genetic history for these stratiform deposits than that for most volcanogenic massive sulphide deposits. Although many authors (Ridler, 1970; Karvinen, 1978) have suggested a syngenetic origin for these deposits, gold and accompanying sulphide minerals in virtually every deposit have undergone at least local remobilization into vein structures. The history of vein formation is multistage (Roberts et al., 1978), and the emplacement of gold and associated sulphides may have been at any time from penecontemporaneous with volcanic rock deposition (2700 ± 50 Ma) to the final stages of the Kenoran orogenic event (2550 Ma). The spread of K-Ar and Rb-Sr ages within Archean rocks indicates that the latter 'orogeny' is not a discrete event, but is really a continuum between depositional, deformational and final thermal events, and thus time of vein formation cannot be readily ascertained.

Gold deposits of the 'intrusive' environment clearly need more study before genetic comparison with the stratiform deposits can be made. However, the well developed secondary isochron (R = 0.45) for some of these deposits may be important in interpreting the origin of the potassium-rich bodies which host many of these veins.

(d) Virtually all deposit classes have some isotopic data which form distinct secondary isochrons. These isochrons generally fall into four distinct groups, and surprisingly, each group is represented in a number of deposit classes. Thus the geological events which operated to generate these secondary isochrons were effective throughout the southern Superior Province and Southern Province regions examined in this study.

Table 8. Slopes of secondary isochrons

Deposit or Group of Deposits	Slope ± 1σ	Group*	Mineral
Kam Kotia	0.48 ± .05	I	galena
Geneva Lake	0.33 ± .15	II	galena
Quemont	0.21 ± .02	III	galena and pyrite
Timagami	0.29 ± .04	II	pyrite
Chibougamau	0.19 ± .03	III	pyrite and galena
O'Connor	0.11 ± .09	IV	pyrite
Cobalt	0.13 ± .03	IV	galena
Stratiform Gold	0.30 ± .02	II	galena
Intrusion-related gold	0.45 ± .03	I	galena

* see discussion below of individual groups.

Four slopes of secondary isochrons recur throughout this report, and seem significant. These slopes, summarized in Table 8, are (i) R ≈ 0.45, (ii) R ≈ 0.30, (iii) R ≈ 0.20, and (iv) R ≈ 0.12. Not included in these average slopes are the leach-residue pairs for gold deposits but Table 6 illustrates that the same slopes are represented by the latter data. Also, the high (R ≈ 0.66) slope of the Stralak data appears unique, and has been discussed previously.

i) Deposits with the R ≈ 0.45 slope include several gold deposits, including most of the syenite-hosted bodies, and the Kam Kotia volcanogenic massive sulphide deposit. These data may indicate that old (~3000 Ma) basement rocks have played an important role in generating the volcanic and syenitic hosts to these deposits, or that such basement rocks have possibly supplied a radiogenic component to the deposits during metamorphism. Examination of the Kam Kotia area for remobilized basement rocks should be undertaken.

ii) Deposits with the R ≈ 0.30 slope include the Geneva Lake volcanogenic massive sulphide, Temagami Mine Road volcanic-hosted pyrite, and stratiform gold deposits. In all cases these deposits have some indication of primary sulphide emplacement at 2700 ± 50 Ma (concomitant with emplacement of their volcanic and/or sedimentary host rocks). Although a variety of interpretations have been presented, the best possibility seems to be a three-stage process, involving (1) primary deposition, (2) Kenoran metamorphism causing some adjustment in isotopic composition, and finally (3) addition of variable amounts of radiogenic lead due to the thermal effects of Nipissing diabase. In the Temagami study, the homogeneity of leach and residue portions of the pyrite may preclude a conventional two or three stage analysis of the data.

iii) The R ≈ 0.20 slope observed in the Quemont and Chibougamau data sets, and also in some of the gold leach-residue data (Don Rouyn and Sigma) is possibly generated by continuous addition of radiogenic lead until the present time; this requires that uranium is incorporated in the analyzed sulphides, a reasonable possibility for the pyrite samples (or that the sulphides

are in contact with a uranium-rich mineral). However, the Quemont samples are galena, and significant uranium has not been detected here. Perhaps some Paleozoic or later event has affected the Quemont deposit, causing sulphide redistribution.

iv) The R ≈ 0.12 slope is apparent in the Timagami-Cobalt area, and may have formed due to redistribution of lead during either the Penokean Orogeny, with continuous addition of radiogenic lead until present, or some Paleozoic event. Closer examination of the Cobalt problem is warranted; the O'Connor data are not necessarily part of a secondary isochron, and may also reflect the addition of common lead to Archean sulphides during metamorphism associated with the cooling of the Nipissing diabase sills.

Model Evaluation

Prior to development of Stacey and Kramers' (1975) two-stage model, analyses of 'conformable' galenas were interpreted by means of a single stage model. Use of the most recently determined physical constants has made application of the single stage model more difficult, because differences between model ages and independently determined wall rock ages are very large (in some cases up to 200 Ma). Unfortunately, data on wall rock ages are presently rather sparse, particularly for Archean terranes.

A large number of samples were suitable for interpretation by the Stacey-Kramers model, as has been discussed in this report. For comparative purposes, calculated model ages of selected samples based on the Stacey-Kramers, Cumming-Richards (1975) continuously changing μ and normal single-stage models, are presented in Table 9.

Clearly, a fairly close fit to wall rock ages is obtained by both the Stacey-Kramers and Cumming-Richards models, and large differences between the model ages and wall rock ages are not common. The Noranda massive sulphide cluster is perhaps the most useful, as the largest number of analyses on genetically well-known deposits, and a U/Pb zircon age, are available for this group. The Stacey-Kramers model gives a closer fit than does the Cumming-Richards to this U/Pb age.

Table 9. Comparison of model ages and μ values by Stacey-Kramers (1975) and Cumming-Richards (1975) models

	Stacey-Kramers		Cumming-Richards	
	Ma	μ	Ma	μ
Centroid Galena**, 22 samples of high base metal massive sulphides (GP I)	2708	8.19	2785	8.76
Average Galena** Noranda massive sulphides (GP I, C)	2728	8.53	2779	8.84
Average Galena** Conformable pyritic sulphide deposits (GP II)	2786	11.30	2663	9.50
Average Galena** Conformable gold deposits (GP IV, A to E)	2697	9.03	2712	8.98
Average Galena* Cobalt silver veins (GP V, A)	2254	10.25	2161	9.63
Galena, New Delhi** (GP V, E) average composition	1808	9.95	1735	9.80
Galena, Kirkland Lake veins (GP II, H3 to H6, average)	2282	10.05	2208	9.54
Galena 1, Geneva Lk. (GP I, G2) 65RF002 average	2790	10.73	2700	9.35
Galena 2, Geneva Lk. (GP I, G2) 65RF001 average	2547	10.05	2484	9.36
Joannes Tp. Galena (GP II, I) pyrite vein	2498	10.09	2428	9.40
Pyrite, Massive sulphide deposits (GP I)	2536	7.22	2705	6.97
Tribag (Gp II, K1) average	1381	10.87	1200	8.93

* Excluding anomalous values which lie on well defined secondary isochrons of low (<0.20) slope.

**Replicates not averaged.

Such studies would be most useful for volcanogenic massive sulphide deposits (Group 1). Some secondary isochrons cannot be interpreted as 'metachrons', due to their steep (~0.45) slopes. Further investigation of the Stralak and Kam Kotia deposits, with particular reference to ages of their host rocks, should be undertaken.

From the secondary isochrons examined in this study, several important aspects arise:

(a) late, and generally unsuspected, events appear to have caused remobilization of lead into veins (Quemont) or re-homogenization of lead due to metamorphism (Geneva Lake).

(b) an older crustal source for at least one major component of the lead can be seen at Stralak and perhaps at Kam Kotia. The validity of classifying the Stralak deposit as a massive sulphide deposit requires further investigation. Alternatively, the general model for massive sulphide genesis, which calls for a well mixed, metal rich brine to transport the metal, may require re-evaluation. The Kam Kotia deposit and nearby veins share a steep secondary isochron which results from the addition of a younger, relatively radiogenic component to an older lead component. The composition of the latter is generally similar to the common lead composition of the massive sulphide cluster, which may have been derived from an older, pre-volcanic source. Examination of the history of the host rocks might establish a 3.06 Ga precursor to them; such basement rocks might be present in the area.

(c) Gold deposits of the conformable stratiform class appear to have formed penecontemporaneously throughout the southern Superior Province, and are generally of the same age as, or slightly younger than, the massive sulphide deposits. The higher average μ value of galena from gold deposits relative to massive sulphides reflects some variation in their relative genetic modes, and may indicate some residence time of the lead in the crust before remobilization into its present form in the deposits. Alternatively, the lead may have originated in a different, more radiogenic (and more mature or older) part of the crust. The isotopic compositions of minor lead in pyrite, together with the galena compositions suggest a more complex genetic history for these stratiform deposits than that for most volcanogenic massive sulphide deposits. Although many authors (Ridler, 1970; Karvinen, 1978) have suggested a syngenetic origin for these deposits, gold and accompanying sulphide minerals in virtually every deposit have undergone at least local remobilization into vein structures. The history of vein formation is multistage (Roberts et al., 1978), and the emplacement of gold and associated sulphides may have been at any time from penecontemporaneous with volcanic rock deposition (2700 ± 50 Ma) to the final stages of the Kenoran orogenic event (2550 Ma). The spread of K-Ar and Rb-Sr ages within Archean rocks indicates that the latter 'orogeny' is not a discrete event, but is really a continuum between depositional, deformational and final thermal events, and thus time of vein formation cannot be readily ascertained.

Gold deposits of the 'intrusive' environment clearly need more study before genetic comparison with the stratiform deposits can be made. However, the well developed secondary isochron (R = 0.45) for some of these deposits may be important in interpreting the origin of the potassium-rich bodies which host many of these veins.

(d) Virtually all deposit classes have some isotopic data which form distinct secondary isochrons. These isochrons generally fall into four distinct groups, and surprisingly, each group is represented in a number of deposit classes. Thus the geological events which operated to generate these secondary isochrons were effective throughout the southern Superior Province and Southern Province regions examined in this study.

Table 8. Slopes of secondary isochrons

Deposit or Group of Deposits	Slope ± 1σ	Group*	Mineral
Kam Kotia	0.48 ± .05	I	galena
Geneva Lake	0.33 ± .15	II	galena
Quemont	0.21 ± .02	III	galena and pyrite
Timagami	0.29 ± .04	II	pyrite
Chibougamau	0.19 ± .03	III	pyrite and galena
O'Connor	0.11 ± .09	IV	pyrite
Cobalt	0.13 ± .03	IV	galena
Stratiform Gold	0.30 ± .02	II	galena
Intrusion-related gold	0.45 ± .03	I	galena

* see discussion below of individual groups.

Four slopes of secondary isochrons recur throughout this report, and seem significant. These slopes, summarized in Table 8, are (i) R ≈ 0.45, (ii) R ≈ 0.30, (iii) R ≈ 0.20, and (iv) R ≈ 0.12. Not included in these average slopes are the leach-residue pairs for gold deposits but Table 6 illustrates that the same slopes are represented by the latter data. Also, the high (R ≈ 0.66) slope of the Stralak data appears unique, and has been discussed previously.

i) Deposits with the R ≈ 0.45 slope include several gold deposits, including most of the syenite-hosted bodies, and the Kam Kotia volcanogenic massive sulphide deposit. These data may indicate that old (~3000 Ma) basement rocks have played an important role in generating the volcanic and syenitic hosts to these deposits, or that such basement rocks have possibly supplied a radiogenic component to the deposits during metamorphism. Examination of the Kam Kotia area for remobilized basement rocks should be undertaken.

ii) Deposits with the R ≈ 0.30 slope include the Geneva Lake volcanogenic massive sulphide, Temagami Mine Road volcanic-hosted pyrite, and stratiform gold deposits. In all cases these deposits have some indication of primary sulphide emplacement at 2700 ± 50 Ma (concomitant with emplacement of their volcanic and/or sedimentary host rocks). Although a variety of interpretations have been presented, the best possibility seems to be a three-stage process, involving (1) primary deposition, (2) Kenoran metamorphism causing some adjustment in isotopic composition, and finally (3) addition of variable amounts of radiogenic lead due to the thermal effects of Nipissing diabase. In the Temagami study, the homogeneity of leach and residue portions of the pyrite may preclude a conventional two or three stage analysis of the data.

iii) The R ≈ 0.20 slope observed in the Quemont and Chibougamau data sets, and also in some of the gold leach-residue data (Don Rouyn and Sigma) is possibly generated by continuous addition of radiogenic lead until the present time; this requires that uranium is incorporated in the analyzed sulphides, a reasonable possibility for the pyrite samples (or that the sulphides

are in contact with a uranium-rich mineral). However, the Quemont samples are galena, and significant uranium has not been detected here. Perhaps some Paleozoic or later event has affected the Quemont deposit, causing sulphide redistribution.

iv) The R ≈ 0.12 slope is apparent in the Timagami-Cobalt area, and may have formed due to redistribution of lead during either the Penokean Orogeny, with continuous addition of radiogenic lead until present, or some Paleozoic event. Closer examination of the Cobalt problem is warranted; the O'Connor data are not necessarily part of a secondary isochron, and may also reflect the addition of common lead to Archean sulphides during metamorphism associated with the cooling of the Nipissing diabase sills.

Model Evaluation

Prior to development of Stacey and Kramers' (1975) two-stage model, analyses of 'conformable' galenas were interpreted by means of a single stage model. Use of the most recently determined physical constants has made application of the single stage model more difficult, because differences between model ages and independently determined wall rock ages are very large (in some cases up to 200 Ma). Unfortunately, data on wall rock ages are presently rather sparse, particularly for Archean terranes.

A large number of samples were suitable for interpretation by the Stacey-Kramers model, as has been discussed in this report. For comparative purposes, calculated model ages of selected samples based on the Stacey-Kramers, Cumming-Richards (1975) continuously changing μ and normal single-stage models, are presented in Table 9.

Clearly, a fairly close fit to wall rock ages is obtained by both the Stacey-Kramers and Cumming-Richards models, and large differences between the model ages and wall rock ages are not common. The Noranda massive sulphide cluster is perhaps the most useful, as the largest number of analyses on genetically well-known deposits, and a U/Pb zircon age, are available for this group. The Stacey-Kramers model gives a closer fit than does the Cumming-Richards to this U/Pb age.

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On the other hand, model ages determined by the Cumming-Richards model for Cobalt galena are closer to the Rb/Sr age of the Nipissing diabase sill, and similarly Tribag samples yield more acceptable Keweenawan ages by this model. The Cumming-Richards model generates a greater spread in model ages than does the Stacey-Kramers, and appears to be more μ sensitive. Thus the Cumming-Richards model generates younger model ages than does the Stacey-Kramers for data of high μ value, and older ages for low μ values.

The data selected by both sets of authors to test the 'fit' of their models includes deposits of rather questionable genetic history. For example, the Daylight and French Bob deposits in southern Africa have recently been shown (Saager and Koppel, 1976) to contain two-stage leads; moreover they are not conformable deposits, and therefore not useful in determining the model. The Manitouwadge area contains the most metamorphosed massive sulphide deposits in southern Superior Province, and the deposits occur in a metamorphic terrain which includes abundant mobilizate.

Although the age of the wall rock for the Manitouwadge deposits is approximately established (Tilton and Steiger, 1969), it is probable that two lead isotope populations exist at Geco (Ostic et al., 1967). The 'younger' population occurs in mobilizate veins. Thus, in view of the partially remobilized nature of the rocks in the entire Manitouwadge area, the samples used for isotopic study must be chosen with care in order to ensure that the isotopic composition is not the result of metamorphic re-equilibration. Similarly the Geneva Lake deposit is genetically obscure, and although probably a volcanogenic deposit, it has undergone considerable remobilization and metamorphism. Galena isotopic data have a bimodal distribution, and the widely quoted wall rock age of 2600 Ma is an average of two dates (2700 Ma and 2500 Ma) suggested (but not determined) by Fairbairn et al. (1960), which may represent a primary and metamorphic age, respectively. Thus both Geneva Lake and Geco (Manitouwadge) are not suitable deposits for use in establishing a lead isotope model.

Finally, the Cobalt deposits are clearly of epigenetic, vein type genesis, and although most models relate the mineralization either directly (Jambor, 1971) or indirectly (Boyle and Dass, 1971) to the Nipissing diabase, some obscurity remains in the history of lead development. Consequently, a model using Cobalt veins as a 'single stage' deposit may be subject to error.

Revised models in future should be established using syngenetic, conformable deposits of well established genetic affinity, situated in areas of low metamorphic grade. The Noranda area and Kidd Creek deposits are most suitable, and new high-precision lead isotope analyses, with accompanying U/Pb zircon studies on wall rocks, should be completed. The Flin Flon deposits are suitable to fix the Aphebian portion of the model in preference to the Cobalt veins, although the Snake Lake deposit (200 km north of Flin Flon) used by Cumming and Richards, is a vein in gabbro (R.B. Cairns, personal communication, 1976) and should be excluded from the model test data.

Care is necessary in interpreting the age of high μ samples, as these may give anomalous ages. Samples with this characteristic may have been generated by short-term two-stage evolution, and may be part of a secondary isochron.

Applications

The use of the lead isotope model to obtain the age of deposits is possible only if rigorous attention is paid to the physical and model limitations. A major physical limitation at the time of analysis for this study was the analytical error problem. With error limits as great as those pertaining to this study, model age determinations based on single samples are of limited use, as these ages may be in error by as much as 150 Ma. Data from any deposit or group of related deposits should be plotted to test for error-line variations, and the 'centroid' of the data spread along that line should be used as the average point for model age calculation. If single data points must be used, then extreme caution should be used in interpretation, particularly if data yield unusually high (~10.0) or low (~7.10) μ values. If the data form a linear array with a slope lower than the ^{204}Pb error line, they may represent an anomalous population. The principal applications are as follows:

(a) Model age determination of conformable massive sulphide deposits is a useful key to relative age differences between volcanic belts. On the basis of lead isotope data, Sangster (1972b) indicated the Aphebian age of the circum-Kisseynew (Flin Flon-Snow Lake) deposits and related volcanic rocks; prior to this work, the deposits were generally accepted as Archean. Subsequent testing elsewhere in the Churchill province has shown the presence of 'old' belts (e.g. Rankin-Ennadai). Additional more precise lead isotope determinations may 'fingerprint' the age and crustal environment (μ) of each volcanic belt within a structural province; the combination of μ and age data may provide discriminating functions between belts.

(b) Lead isotopes may be used to classify deposits, and many of the groups of deposits selected for this study have characteristic isotope 'signatures'. For example, massive sulphide deposits in Superior Province are characterized by galena model ages of 2675-2750 Ma, and μ values of 7.4 to 9.4. Galena samples from pyritic deposits with low base metal contents are characterized by similar ages, but high μ (av. 10.2) values. Galena samples from conformable gold deposits have similar model ages, but higher μ values (av. 8.8) than galena samples from massive sulphide deposits. Although accurate discrimination of these deposit types on the basis of μ may not always be possible, within a restricted area some effective separation may be possible. The higher μ for gold and pyritic deposits may indicate longer residence time of lead in a crustal source rock before mobilization into the present deposit as galena; lead in massive sulphide deposits probably has a very short residence time in the immediate source rocks.

Effective discrimination of intrusion-related and conformable gold deposits may be accomplished by lead isotope studies, as the former have younger, commonly anomalous, model ages, and high μ values, relative to the latter. Again, the necessity of analyzing several samples from a single deposit is obvious in order to test for the presence of a secondary isochron.

Some deposit classes have lead isotope compositions which yield unique and well defined secondary isochrons. For example, the silver veins of the Cobalt area have lead isotopic compositions which cluster around the 2100 Ma isochron, and a second population which forms a good secondary isochron. Galena from a new occurrence could be

analyzed to determine its relationship to these established populations, and thus assign the deposit to the Cobalt, or some other class.

Deposits which contain galena samples with extremely anomalous compositions, such as those from the lead-zinc-barite veins at Thunder Bay (Russell and Farquhar, 1960) might contain uranium, or the source rocks for such lead might be anomalously rich in uranium. Recent examination of the Thunder Bay veins (Ruzicka, 1976; Franklin, 1978) has documented their anomalous uranium concentration and, although the parent-daughter relationship has not been studied, the large amount of radiogenic lead in their galena samples must have been contributed from a very U-rich system. Further investigation of this system is necessary, but analyses of galena in even minor occurrences might prove useful as a guide to uranium deposits or uranium-rich 'source rocks'.

In summary, lead isotopic studies have as much or more use as tools to refine the genesis of deposits as they have to determine the age of mineralization. Our findings are, in all cases, preliminary; each isotopic 'signature', whether it is a cluster of isotopic compositions, or a secondary isochron, needs further testing, and refinement using today's superior analytical techniques. Nevertheless, our findings clearly require that the genetic models assigned to deposits in Superior and Southern provinces need further refinement.

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APPENDIX

Tables I, II and A.1 to A.5, Figures A.1 to A.5 are in pocket

TABLE I

T1003 (BROKEN HILL NO. 1)

Replicate Analysis

Geological Survey of Canada

	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1.	16.054	15.428	35.816
2.	16.139	15.523	36.112
3.	16.004	15.374	35.603
4.	16.041	15.423	35.701
5.	15.938	15.306	35.466
6.	15.984	15.354	35.507
7.	16.128	15.532	36.024
8.	16.014	15.414	35.704
9.	15.926	15.326	35.507
10.	16.042	15.423	35.744
11.	16.033	15.446	35.696
12.	16.052	15.481	35.888
13.	15.977	15.421	35.116
14.	15.854	15.228	35.329
15.	15.922	15.278	35.377

TABLE II

Deposit List and Text Reference

Deposit Name	Appendix Table	Deposit Group and Number	NTS	Page
Adams	A.2	B-2	32D4	19
Alma Twp.	A.4	I-3	42A2	
Amulet "A"	A.1	C-8	32D6	
Amulet "C"	A.1	C-7	32D6	
Aunor	A.4	B-4	42A6	
Barvue	A.1	E-2	32C5	16
Beattie	A.4	G-4	32D11	
Benoit Twp.	A.2	H-8	42A4	20
Black Twp	A.2	H-1	42A8	20
Botha Twp.	A.2	C-4	41I13	19
Broulan Reef	A.4	B-8	42A11	27
Buffonto	A.4	I-1	32D5	28
Campbell Chibougamau	A.3	A-3	32G16	23
Canal Lake Area	A.5	I-6	24K5	

Deposit Name	Appendix Table	Deposit Group and Number	NTS	Page
Chadbourne	A.4	G-1	32D3	28
Chibougamau Explorers	A.4	F-1	32F8	
Coniagas	A.1	B-1	32F8	16
Copper Rand Chibougamau	A.3	A-2	32G16	
Cramolet Lake	A.5	I-2	23013	
Dane	A.2	H-5	32D5	20
Deer Horn	A.5	A-4	31M4	
D'Eldona	A.1	C-9	32D7	16
Delnite	A.4	B-5	42A6	25
Dodette Lake Area	A.5	I-3	23J5	
Dome	A.4	B-7	42A6	25
Don Rouyn	A.4	G-5	32D3	28
Doré Lake	A.2	A-2	32G16	
Dufresnoy	A.1	C-11	32D3	
Dumagami	A.1	C-10	32D1	16
East Sullivan	A.1	E-1	32C4	16
Fabre Twp.	A.2	J-1	31M3	23
Flavelle Twp.	A.4	I-1	42A2	28
Frederickson Lake	A.5	I-5	23O4	
Geco	A.1	F-1	42F4	34
Geneva Lake	A.1	G-2	41I13	17
Godfrey Twp.	A.2	G-2	42A12	17
Harker	A.4	I-5	32D5	27
Hermiston-McCauley	A.4	C-2	31M4	27
Horne H Zone	A.1	C-4	32D6	22
Horne 5 Zone	A.1	C-1	32D6	15
Horseshoe Lake	A.5	A-1	41P6	
Hudson Bay	A.5	A-2	31M4	
Jameson Twp	A.2	G-1	42A12	17
Jerome	A.4	J-2	41P14	27
Joannes Twp.	A.2	I-1	32D2	22
Joutel	A.1	D-3	32F6	
Kam Kotia	A.1	A-1	42A12	14
Kenogami	A.5	B-1	42A1	29
Kerr Addison	A.4	A-1	32D4	27
Kidd Creek	A.1	A-2	42A11	16
Kitchener Twp.	A.2	C-5	41I14	19
Lake Dufault	A.1	C-5	32D6	16
Langis	A.5	A-5	31M5	30
Leech Lake	A.5	F-2	41I3	
Little Dan	A.4	C-1	31M4	28
Little Nighthawk Lake	A.2	G-3	42A3	
Lorraine	A.2	J-2	31M6	30
Lowe	A.2	H-6	32D4	20
Luchak	A.5	G-1	41J5	

Deposit Name	Appendix Table	Deposit Group and Number	NTS	Page
Mallard Lake	A.5	A-3	31M13	
Mammouth	A.2	F-1	42C2	20
Marbridge	A.3	C-1	32D3	23
Marbridge	A.2	E-1	32D3	24
Marshay Twp.	A.2	C-3	41P3	19
Mattagami	A.1	D-1	32F12	15
Matarrow	A.2	H-4	41P15	20
McIntyre	A.4	B-3	42A6	
McIntyre	A.4	J-1	42A6	
Michipicoten	A.4	D-1	41O15	28
Midas	A.5	F-1	41I6	
Millar Lake Basin	A.5	A-6	41P10	30
Mistassini	A.5	C-1	32I	
Mistassini Post	A.5	C-2	32I4	
Mobrun	A.1	C-12	32D7	
Mongowin	A.5	G-3	41I4	
Muscocho	A.5	C-3	32I4	
New Delhi	A.5	E-1	42P1	30
New Hosco	A.1	D-4	32F13	
New Marlon	A.4	G-2	32D3	28
New Rouyn Merger	A.4	A-2	32D2	28
Norbeau	A.4	K-1	32G16	
Normetal	A.1	C-6	32D14	16
Northland	A.2	C-2	31M4	
O'Connor	A.3	B-1	31M4	24
Opemiska	A.3	A-1	32G15	23
Orchan	A.1	D-2	32F12	15
Pamour	A.4	B-1	42A11	28
Paymaster	A.4	B-6	42A6	25
Pays Plat Gravel River	A.2	L-1	42D13	23
Peter Lake	A.2	D-2	41P15	19
Pitcher Mobi	A.2	A-1	32G14	19
Portage	A.3	A-4	32G16	
Prudhomme No. 1	A.5	I-4	24K4	
Quemont	A.1	C-3	32D3	
Quemont Vein	A.2	I-2	32D3	22
Rainville	A.4	G-3	32D3	
Rangers Lake	A.5	G-2	41J13	
Roche	A.2	B-1	32D4	19
Romanet Lake Area	A.5	I-1	24B4	
Rush Lake	A.2	D-1	41P16	19
St. Pierre	A.2	H-2	32D4	20
Shuniah	A.5	D-1	52A6	
Sigma	A.4	H-1	32C4	29
Silvermaque	A.5	H-2	41J2	
Solmes	A.2	H-7	42A8	20

Deposit Name	Appendix Table	Deposit Group and Number	NTS	Page
Smith-Thorne	A.4	B-2	41O16	25
Stanrock	A.5	H-1	41J2	
Stralak	A.1	G-3	41I13	17
Sullivan	A.4	H-2	32C4	27
Surimau Twp.	A.4	E-2	32D1	
Taché Lake	A.4	K-2	32G16	
Temagami Copperfields	A.1	G-1	41I16	
Temagami Mine Road	A.2	C-1	41I16	20
Tribag	A.2	K-1	41N2	21
Upper Canada	A.4	I-4	32D4	27
Vauquelin Twp.	A.4	E-1	32C3	28
Wolf Lake	A.2	H-3	42A1	20

Table A.1

High Cu-Zn content massive sulphide deposits in Archean strata

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
A) TIMMINS AREA													
1) KAM KOTIA copper-zinc mine													
48°31'45" 81°36'10" 42A/12 Robb and Jameson Tp. 22 km NW of Timmins, Ontario.	63RF 0124	Pyrite (R)	II	1.669	21.58	23.35	53.40	12.93	13.99	32.00	1.082	2.475	
				1.679	21.63	23.35	53.34	12.88	13.91	31.76	1.080	2.466	
Deposits are lenses of near massive pyrite containing chalcopyrite and sphalerite. Host rock are steeply-dipping, steeply-schistose, felsic volcanic rocks with minor basic volcanic rocks. Andesite dykes cut the deposit. Argillaceous graphitic and limy tuffaceous sediments are locally adjacent to deposits. Deposits contain dense fine grained pyrite and pyrite nodules. Total production was 5 995 270 tonnes of 1.08% Cu, 1.18% Zn, 2.58 g/tonne Ag (Pyke and Middleton, 1971).	63RF 0124	Pyrite (L)	II	1.629	21.51	23.38	53.48	13.20	14.35	32.83	1.087	2.486	
				1.639	21.56	23.38	53.42	13.15	14.27	32.59	1.085	2.478	
	63RF 0124	Galena	II	1.598	21.62	23.35	53.43	13.53	14.61	33.44	1.080	2.471	
				1.608	21.67	23.35	53.37	13.48	14.52	33.19	1.078	2.463	
	64RF 0588	Galena	II	1.577	21.81	23.28	53.33	13.83	14.76	33.82	1.067	2.445	
				1.587	21.86	23.28	53.27	13.78	14.67	33.57	1.065	2.437	
	64RF 0273	Galena	II	1.543	22.30	23.24	52.92	14.45	15.06	34.30	1.042	2.373	
				1.552	22.35	23.24	52.86	14.40	14.97	34.05	1.040	2.365	
2) KIDD CREEK (Texasgulf Limited) zinc-copper-silver-lead mine.													
48°41'54" 81°21'30" 42A/11 Kidd Tp. 22 km N of Timmins, Ontario.	65RF 0529	Galena	II	1.605	21.41	23.35	53.64	13.34	14.55	33.42	1.091	2.505	
				1.615	21.46	23.35	53.56	13.29	14.46	33.16	1.088	2.496	
Deposit is a composite lens 700 m long, up to 150 m thick of near massive sulphides trending north, and occurring in a volcaniclastic unit which includes some graphitic argillite. This unit is overlain by andesite and underlain by massive and fragmented rhyolite. The bulk of the massive ore is composed mainly of pyrite and sphalerite but chalcopyrite ore occurs along the eastern side; the south lobe is very rich in sphalerite and contains galena at its north end; graphitic, pyritic argillite occurs along the central section and the west margin of the larger north lobe and contains pyrite nodules; massive pyrite is characteristically very fine-grained (Walker and Mannard, 1974). Total production plus reserves are 116 549 500 tonnes of 2.38% Cu, 0.30% Pb, 8.30% Zn, 86.6 g/tonne Ag.	65RF 0557	Galena	II	1.606	21.39	23.38	53.62	13.32	14.56	33.39	1.093	2.507	
				1.616	21.44	23.39	53.56	13.27	14.47	33.15	1.091	2.498	
B) CHIBOUGAMAU AREA													
1) CONIAGAS silver-zinc-lead mine													
49°30'00" 76°10'00" 32F/8 Lesuer Tp. 115 km E of Mattagami, Quebec.	63RF 0474	Galena	GSC	1.654	21.37	23.22	53.76	12.92	14.04	32.50	1.086	2.515	
				1.655	21.42	23.23	53.69	12.94	14.04	32.44	1.085	2.507	
Irregular bodies, contorted layers and lenses of pyrite, sphalerite and galena in metamorphosed felsic breccia and tuff, with minor sulphide in altered footwall andesite. Total production plus reserves are 728 135 tonnes of 10.2% Zn, 1.04% Pb, 160 g/tonne Ag.				1.612	21.37	23.31	53.71	13.26	14.46	33.32	1.090	2.513	
				1.613	21.42	23.32	53.64	13.28	14.46	33.25	1.089	2.504	
				1.630	21.43	23.36	53.57	13.15	14.33	32.87	1.090	2.500	
				1.630	21.43	23.36	53.57	13.15	14.33	32.87	1.090	2.500	

Table A1 (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
C) ROUYN-NORANDA AREA													
1) HORNE 5 ZONE Noranda Mines Limited copper-gold mine													
48°15'15" 79°00'30" 32D/6 Rouyn Tp., Noranda, Quebec	63RF 0031	Pyrite (R)	GSC	1.624	21.46	23.36	53.55	13.21	14.38	32.96	1.088	2.495	
				1.625	21.51	23.38	53.49	13.23	14.38	32.91	1.087	2.487	
Extensive lens of pyrite with minor sphalerite, chalcopyrite and gold in blocks and in disseminated form, occurring in rhyolite tuff and breccia. Sulphide zone extends down-dip for over 2100 m, a maximum strike length of 900 m and an average thickness of 30 m (Sinclair, 1971).	63RF 0031	Pyrite (L)	GSC	1.616	21.53	23.32	53.54	13.31	14.43	33.12	1.083	2.487	
				1.617	21.58	23.33	53.47	13.34	14.43	33.07	1.081	2.478	
	63RF 0032	Pyrite (L)	GSC	1.622	21.49	23.31	53.57	13.25	14.37	33.02	1.085	2.492	
				1.623	21.54	23.33	53.51	13.27	14.37	32.96	1.083	2.484	
	63RF 0032	Pyrite (R)	GSC	1.633	21.58	23.29	53.49	13.22	14.26	32.76	1.079	2.478	Low lead
				1.634	21.63	23.31	53.43	13.24	14.26	32.69	1.078	2.470	
	63RF 0033	Sphale (L)	GSC	1.645	21.54	23.33	53.48	13.10	14.19	32.51	1.083	2.483	
				1.646	21.59	23.35	53.42	13.11	14.18	32.45	1.081	2.474	
	63RF 0033	Sphale (R)	GSC	1.510	23.52	22.33	52.64	15.58	14.79	34.87	0.949	2.238	Low lead -
				1.511	23.57	22.34	52.57	15.60	14.79	34.79	0.948	2.230	Questionable
	63RF 0033	Sphale (L)	GSC	1.633	21.55	23.27	53.55	13.20	14.25	32.79	1.080	2.485	
				1.634	21.60	23.28	53.48	13.22	14.25	32.73	1.078	2.476	
	63RF 0033	Sphale (U)	GSC	1.629	21.42	23.33	53.62	13.15	14.32	32.91	1.089	2.504	
				1.630	21.47	23.35	53.56	13.17	14.32	32.85	1.087	2.495	
2) WEST MACDONALD mine (former zinc-minor copper-pyrite producer)													
48°19'35" 78°57'10" 32D/7 Dufresnoy Tp. 9.6 km NE of Noranda, Quebec	63RF 0511	Pyrite (U)	II	1.623	21.57	23.37	53.43	13.29	14.40	33.10	1.083	2.477	
				1.633	21.62	23.38	53.37	13.24	14.31	32.86	1.081	2.469	
Deposit is a body of massive pyrite with sphalerite and minor amounts of chalcopyrite in felsic volcanic breccia. The ore exposed on surface is brecciated and contains much very fine grained, laminated pyrite. Total production plus reserves are 3 450 000 tonnes of 4.21% Zn, 24.0 g/tonne Ag, and 1.03 g/tonne Au.													
3) QUEMONT copper-gold-zinc mine													
48°15'25" 79°00'30" 32D/3 Rouyn Tp. 1.6 km N of Noranda, Quebec.	63RF 0048	Pyrrho (L)	GSC	1.618	21.46	23.34	53.57	13.27	14.43	33.12	1.088	2.496	
				1.619	21.51	23.36	53.51	13.28	14.43	33.05	1.086	2.488	
Pyrite-sphalerite-pyrrhotite-chalcopyrite lenses in chloritic-rhyolite breccia beneath massive rhyolite.	63RF 0048	Pyrrho (R)	GSC	1.624	21.45	23.35	53.58	13.20	14.37	32.99	1.089	2.498	
				1.625	21.50	23.36	53.51	13.23	14.38	32.93	1.087	2.490	
The strata are cut by quartz-feldspar porphyry and massive rhyolite dykes. The Horne Creek fault cuts the southern part of the property (Weeks, 1967). Total production was 13 921 543 tonnes of 1.31% Cu, 2.43% Zn, 4.04 g/tonne Au, 9.7 g/tonne Ag.	63RF 0049	Pyrite (R)	GSC	1.568	22.13	23.05	53.25	14.12	14.70	33.97	1.041	2.406	Low lead -
				1.569	22.18	23.06	53.19	14.14	14.70	33.90	1.040	2.398	Questionable
	63RF 0049	Pyrite (L)	GSC	1.536	22.39	22.72	53.35	14.58	14.79	34.73	1.014	2.382	Low lead -
				1.537	22.44	22.73	53.29	14.60	14.79	34.67	1.013	2.375	Questionable
	63RF 0049	Pyrite (U)	GSC	1.562	22.20	22.87	53.36	14.21	14.64	34.15	1.030	2.404	Low lead -
				1.563	22.25	22.89	53.30	14.23	14.64	34.09	1.029	2.395	Questionable
4) HORNE H ore zone, (NORANDA) copper-gold mine													
48°15'13" 79°00'45" 32D/6 Rouyn Tp. Noranda, Quebec	63RF 0036	Pyrrho (L)	GSC	1.462	23.42	22.13	52.99	16.02	15.13	36.24	0.945	2.263	Low lead
				1.463	23.47	22.14	52.92	16.04	15.13	36.17	0.943	2.255	
Large massive pipe-like pyrrhotite-pyrite-chalcopyrite body in rhyolite breccia (Hodge, 1967). Approximately 53 513 000 tonnes of 2.2% Cu, 4.9 g/tonne Au, and 9.7 g/tonne Ag were mined.		Pyrrho (L)	GSC	1.478	23.44	22.19	52.89	15.86	15.01	35.78	0.947	2.256	Low lead
				1.478	23.44	22.19	52.89	15.86	15.01	35.71	0.945	2.248	
	63RF 0010	Galena	GSC	1.622	21.42	23.37	53.59	13.20	14.41	33.04	1.091	2.502	
				1.622	21.47	23.38	53.52	13.23	14.41	32.97	1.089	2.493	
5) LAKE DUFAULT copper-zinc-silver mine													
48°21'05" 79°03'00" 32D/6 Dufresnoy Tp. 11 km N of Noranda, Quebec.	63RF 0041	Galena	GSC	1.601	21.41	23.37	53.62	13.37	14.60	33.49	1.091	2.504	
				1.602	21.46	23.38	53.55	13.39	14.60	33.43	1.090	2.496	
Stratiform massive pyrite-sphalerite-chalcopyrite-pyrrhotite body in rhyolite beneath andesite (Spence and Rosen-Spence, 1975). Total production plus reserves are 3 737 084 tonnes of 2.78% Cu, 4.76% Zn, 33 g/tonne Ag, 0.54 g/tonne Au (Spence and de Rosen-Spence, 1975).	63RF 0038	Pyrite (R)	GSC	1.611	21.44	23.35	53.60	13.31	14.49	33.27	1.089	2.500	
				1.612	21.49	23.36	53.53	13.33	14.49	33.21	1.087	2.491	
	63RF 0038	Pyrite (L)	GSC	1.618	21.41	23.35	53.63	13.23	14.43	33.14	1.091	2.505	
				1.619	21.46	23.36	53.56	13.25	14.43	33.09	1.089	2.496	
6) NORMETAL copper-zinc mine													
49°00'00" 79°21'55" 32D/14 Desmeloizes Tp. About 88 km NNW of Noranda, Quebec.	63RF 0421	Galena	II	1.611	21.33	23.35	53.71	13.24	14.49	33.34	1.095	2.518	
				1.621	21.38	23.35	53.65	13.19	14.41	33.10	1.092	2.510	
Deposit is a steeply-plunging ribbon of massive pyrite, sphalerite-rich on the south side and chalcopyrite-rich on the north side, concordant with metamorphosed tuff of near amphibolite grade with strike ESE. K-Ar date on phlogopite intergrown with chalcopyrite is 2.55×10^9 years (Bertrand and Hutchinson, 1975). Total production was 10 104 685 tonnes of 2.1% Cu, 5.1% Zn, 0.4 g/tonne Au and 33.9 g/tonne Ag.														

Table A.1 (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
7) AMULET "C" zone, copper-zinc-silver-gold mine (former producer)													
48°18'35" 79°04'35" 32D/6 Dufresnoy Tp. 8 km NW of Noranda, Quebec.	63RF 0305	Galena	II	1.610 1.620	21.45 21.50	23.39 23.39	53.55 53.49	13.32 13.27	14.53 14.44	33.26 33.02	1.090 1.088	2.497 2.488	
Deposits were small lenses of massive pyrite-sphalerite-chalcopyrite-pyrrhotite along an east-dipping contact between rhyolite and overlying andesite: a thin bed of tuff occurs along this contact (Spence and de RosenSpence, 1975). Total production from Amulet A (below) and C zones was 4 087 100 tonnes of 5.12% Cu, 5.47% Zn, 0.5 g/tonne Au, and 89.9 g/tonne Ag.	63RF 0256	Galena	II	1.607 1.617	21.48 21.53	23.38 23.38	53.53 53.47	13.31 13.26	14.55 14.46	33.31 33.07	1.088 1.086	2.492 2.484	
8) AMULET "A" zone, copper-zinc-silver-gold mine (former producer)													
48°18'30" 79°04'05" 32D/6 Dufresnoy Tp. 8 km NW of Noranda, Quebec.	63RF 0266	Galena	II	1.608 1.618	21.42 21.47	23.33 23.35	53.62 53.56	13.32 13.27	14.52 14.44	33.35 33.10	1.090 1.088	2.503 2.495	
Deposit was a concordant lens of massive pyrite-sphalerite-chalcopyrite in andesite above the much larger Lower A orebody which was at the base of the andesite at the contact with underlying rhyolite. Chalcopyrite and pyrrhotite occur in highly altered fractured rock beneath the massive ore (Spence and de Rosen-Spence, 1975).													
9) DELDONA copper-zinc-silver-gold mine (past producer, Delbridge Mines Ltd.)													
48°16'00" 78°57'56" 32D/7 Rouyn Tp. 4.8 km NE of Noranda, Quebec.	63RF 0292	Galena	II	1.604 1.614	21.41 21.46	23.37 23.37	53.62 53.56	13.35 13.30	14.57 14.48	33.43 33.19	1.092 1.089	2.504 2.496	
Deposit discovered in 1966 is a steeply-dipping lens of massive pyrite-sphalerite along a northerly trending contact between the host rhyolite breccia and overlying rhyolite. Chalcopyrite is present mainly at the footwall of massive ore and in underlying breccia ore. Gold and silver contents are relatively high for deposits of this class. The small deposit or deposits formerly mined as direct shipping ore are separate from and about 300 m north of the new body but are presumably related to it and the contact (Boldy, 1968). Total production was 370 000 tonnes of 11.97% Zn, 1.03% Cu, 107 g/tonne Au and 89.9 g/tonne Ag.													
10) DUMAGAMI gold-copper prospect													
48°13'50" 78°26'20" 32D/1 Bousquet Tp. 42 km E of Noranda, Quebec.	63RF 0297	Galena	II	1.618 1.628	21.42 21.47	23.39 23.39	53.58 53.51	13.24 13.19	14.46 14.37	33.11 32.87	1.092 1.090	2.501 2.493	
Deposit is a sheet of near-massive pyrite containing chalcopyrite, sphalerite, galena and gold values in steeply dipping east-trending schistose felsic metavolcanic rocks including tuff and agglomerate. Reserves are estimated at 1 016 384 tonnes grading on the average 0.29% Cu, 4.9 g/tonne Au, 14.9 g/tonne Ag (C.M.H., 1972).													
11) DUFRESNOY zinc-copper-silver prospect													
48°17'35" 79°04'00" 32D/3 Dufresnoy Tp. 6.4 km NW of Noranda, Quebec.	63RF 0043	Sphale (R)	GSC	1.630 1.631	21.56 21.61	23.34 23.35	53.47 53.41	13.22 13.25	14.32 14.32	32.80 32.74	1.083 1.081	2.480 2.471	
Pyrite-sphalerite-chalcopyrite body in rhyolite.	63RF 0043	Sphale (L)	GSC	1.613 1.614	21.48 21.53	23.36 23.38	53.54 53.48	13.32 13.34	14.49 14.48	33.20 33.13	1.088 1.086	2.493 2.484	
12) MOBRUN zinc-copper prospect													
48°24'00" 78°54'40" 32D/7 Dufresnoy Tp. 17.5 km NE of Noranda, Quebec.	63RF 0195	Pyrite (U)	II	1.623 1.633	21.53 21.58	23.39 23.39	53.47 53.40	13.27 13.21	14.41 14.33	32.95 32.71	1.086 1.084	2.484 2.475	
Deposit is a lens of massive very fine grained pyrite containing sphalerite and small amounts of chalcopyrite which also occurs in disseminated sulphides in chloritic rocks marginal to the massive body. Host rocks are felsic volcanics, probably of pyroclastic origin, near andesite. Reserves are estimated at 2 721 000 tonnes having an average grade of 0.69% Cu and 2.18% Zn, 1.34 g/tonne Au, 15.9% g/tonne Ag.													

Table A.1 (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
D) MATAGAMI LAKE AREA													
1) MATTAGAMI zinc-copper mine													
49°43'20" 77°44'20" 32F/12 Galinee Tp. About 8 km SW of Matagami, Quebec.	63RF 0012	Sphale (L)	GSC	1.630	21.35	23.32	53.70	13.10	14.30	32.94	1.092	2.516	
				1.631	21.40	23.33	53.64	13.12	14.31	32.88	1.090	2.507	
Strata-bound massive pyrite-sphalerite-chalcopyrite body at top of Watson Lake group (felsic volcanic rocks), overlain by cherty tuffite horizon and the Wabassee group (mafic and intermediate lava); deposit is near layered gabbro and anorthosite of the Bell River complex (Roberts, 1975). Total production plus reserves are 23 853 879 tonnes of 7.8% Zn, 0.4% Cu, 23.14 g/tonne Ag, and 3.86 g/tonne Au.	63RF 0012	Sphale (R)	GSC	1.639	21.40	23.32	53.65	13.05	14.23	32.73	1.090	2.507	
				1.640	21.45	23.33	53.58	13.08	14.23	32.67	1.088	2.498	
	63RF 0012	Pyrrho (R)	GSC	1.628	21.29	23.30	53.78	13.08	14.31	33.03	1.095	2.526	
				1.629	21.30	23.32	53.72	13.10	14.31	32.97	1.093	2.517	
	63RF 0012	Pyrrho (L)	GSC	1.634	21.37	23.32	53.68	13.08	14.27	32.85	1.091	2.512	
				1.635	21.42	23.33	53.61	13.10	14.27	32.79	1.090	2.503	
	63RF 0012	Galena	GSC	1.625	21.35	23.30	53.72	13.14	14.33	33.05	1.091	2.516	
				1.626	21.40	23.32	53.66	13.16	14.34	32.99	1.090	2.507	
	63RF 0013	Pyrite (L)	GSC	1.635	21.52	23.25	53.60	13.16	14.22	32.78	1.080	2.490	
				1.636	21.57	23.26	53.53	13.18	14.22	32.72	1.079	2.482	
	63RF 0013	Pyrite (L)	GSC	1.617	21.55	23.26	53.57	13.33	14.39	33.14	1.079	2.486	
				1.618	21.60	23.28	53.51	13.35	14.38	33.07	1.078	2.477	
	63RF 0013	Pyrite (R)	GSC	1.638	21.43	23.30	53.63	13.08	14.23	32.74	1.087	2.502	Low lead
				1.639	21.48	23.32	53.57	13.10	14.22	32.68	1.086	2.494	
	63RF 0012	Galena	GSC	1.610	21.24	23.27	53.88	13.30	14.45	33.47	1.096	2.537	
				1.619	21.31	23.30	53.78	13.32	14.45	33.41	1.093	2.528	
	63RF 0012	Galena	GSC	1.608	21.21	23.25	53.94	13.19	14.46	33.54	1.096	2.543	
				1.617	21.28	23.28	53.83	13.16	14.46	33.48	1.094	2.534	
2) ORCHAN zinc-copper mine													
49°42'30" 77°43'20" 32F/12 Galinee Tp. About 8 km SW of Matagami, Quebec.	63RF 0581	Galena	GSC	1.634	21.38	23.33	53.76	13.02	14.28	32.90	1.096	2.526	
				1.633	21.41	23.32	53.64	13.04	14.28	32.84	1.096	2.517	
Strata-bound pyrite-pyrrhotite-sphalerite-chalcopyrite deposit at contact between underlying porphyritic rhyolite (Watson Lake group) and overlying andesite (Wabassee group) (Sharpe, 1968). Total production plus reserves are 4 086 942 tonnes of 10.22% Zn and 1.06% Cu.	63RF 0016	Pyrrho (L)	GSC	1.620	21.43	23.28	53.68	13.23	14.37	33.15	1.086	2.505	
				1.621	21.48	23.29	53.61	13.25	14.37	33.07	1.085	2.496	
	63RF 0016	Pyrrho (U)	GSC	1.609	21.38	23.21	53.80	13.29	14.43	33.44	1.086	2.516	
				1.610	21.43	23.23	53.74	13.31	14.42	33.37	1.084	2.508	
	63RF 0581	Galena	GSC	1.604	21.23	23.25	53.91	13.24	14.50	33.61	1.095	2.539	
				1.613	21.30	23.29	53.81	13.26	14.50	33.55	1.093	2.530	
	63RF 0581	Galena	GSC	1.609	21.26	23.26	53.87	13.21	14.46	33.48	1.094	2.534	
				1.618	21.33	23.29	53.77	13.23	14.46	33.42	1.091	2.525	
3) JOUTEL zinc-copper mine													
49°27' 78°21' 32F/6 Joutel Tp. 38 miles SW of Matagami, Quebec.	63RF 0028A	Pyrite (L)	GSC	1.624	21.42	23.35	53.60	13.19	14.38	32.99	1.090	2.502	
				1.625	21.47	23.37	53.54	13.21	14.38	32.94	1.088	2.494	
Strata-bound massive pyrite-sphalerite-chalcopyrite deposit enclosed by felsic volcanic rocks, closely associated with highly deformed cherty tuffite.	63RF 0028A	Pyrite (R)	GSC	1.612	21.40	23.34	53.64	13.28	14.48	33.28	1.091	2.507	
				1.613	21.45	23.36	53.58	13.30	14.48	33.21	1.089	2.498	
Total production was 1 286 300 tonnes of 2.16% Cu, and additional 399 260 tonnes of 8.7% Zn.	63RF 0028B	Pyrite (R)	GSC	1.595	21.41	23.23	53.76	13.42	14.57	33.71	1.085	2.512	
				1.596	21.46	23.25	53.70	13.44	14.56	33.64	1.083	2.502	
	63RF 0028B	Pyrite (L)	GSC	1.578	22.02	22.93	53.47	13.95	14.53	33.87	1.041	2.428	
				1.579	22.07	22.94	53.41	13.98	14.53	33.82	1.040	2.420	
	63RF 0028B	Pyrite (R)	GSC	1.595	21.49	22.26	53.65	13.47	14.58	33.64	1.083	2.497	
				1.596	21.54	23.27	53.58	13.50	14.58	33.57	1.080	2.487	
4) NEW HOSCO zinc-copper mine													
49°47'40" 77°50'30" 32D/13 Daniel Tp. 10 miles NW of Matagami, Quebec.	63RF 0019	Pyrite (R)	GSC	1.610	21.50	23.28	53.61	13.36	14.46	33.30	1.083	2.493	
				1.611	21.55	23.29	53.55	13.37	14.46	33.23	1.081	2.485	
Pyrite-pyrrhotite-sphalerite-chalcopyrite deposit underlain by salic agglomerate, overlain by cherty tuffite (Graham, 1960). Total production plus reserves are 1 954 800 tonnes of 1.61% Zn, and 1.78% Cu.	63RF 0019	Pyrite (U)	GSC	1.623	21.51	23.27	53.59	13.26	14.34	33.03	1.082	2.491	
				1.624	21.56	23.29	53.53	13.27	14.34	32.96	1.080	2.483	
E) VAL D'OR AREA													
1) EAST SULLIVAN copper-zinc mine													
48°06'25" 77°43'20" 32C/4 Bourlamaque Tp. 4 miles SE of Val d'Or, Quebec.	64RF 0620	Galena	II	1.634	21.42	23.40	53.54	13.11	14.32	32.77	1.092	2.500	
				1.644	21.47	23.41	53.48	13.06	14.24	32.53	1.090	2.491	
Strata-bound bodies of massive pyrite, pyrrhotite, chalcopyrite and sphalerite in metamorphosed, sheared and altered volcanic rocks including pyroclastics and rhyolite (Assad, 1958).				1.603	21.48	23.40	53.52	13.40	14.60	33.39	1.089	2.492	
				1.613	21.53	23.40	53.46	13.35	14.51	33.15	1.087	2.483	
			GSC	1.621	21.43	23.38	53.57	13.22	14.42	33.05	1.091	2.500	
Total production was 15 123 724 tonnes of 0.9% Cu, 0.5% Zn, 0.18 g/tonne Au, and 5.38 g/tonne Ag.				1.628	21.47	23.41	53.50	13.24	14.42	32.99	1.090	2.492	
				1.612	21.38	23.34	53.67	13.26	14.48	33.29	1.092	2.510	
				1.619	21.42	23.37	53.59	13.28	14.48	33.23	1.090	2.502	

Table A.1 (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
2) BARVUE zinc mine (former open pit producer)													
48°31'10" 77°41'54" 32C/5 Barraute Tp. 40 km N of Val d'Or, Quebec.	63RF 0166	Galena	II	1.604	21.34	23.37	53.68	13.30	14.57	33.47	1.095	2.515	
				1.614	21.39	23.38	53.62	13.25	14.48	33.22	1.093	2.507	
Deposit is tabular and concordant in schistose felsic pyroclastic rocks (Cornwall, 1972). Total production was 5 080 107 tonnes of 2.5% Zn, .0024% Pb, 8.22 g/tonne Ag.													
F) MANITOUWADGE AREA													
1) GECO copper-zinc-silver mine													
49°09' 85°47' 42F/4 Gemmell Tp. 3.2 km NE of Manitouwadge, Ontario.	66RF 0156	Galena	GSC	1.596	21.27	23.29	53.85	13.32	14.59	33.74	1.095	2.531	
				1.605	21.33	23.33	53.74	13.34	14.59	33.68	1.093	2.522	
Strata-bound, massive lens of pyrite, sphalerite, pyrrhotite and chalcopyrite and associated disseminated pyrite, pyrrhotite, chalcopyrite and minor sphalerite in muscovite-quartz schist. Ore was probably metamorphosed along with Archean strata during Kenoran Orogeny (Pye, 1960). Total production polus reserves are 47 426 277 tonnes of 1.46% Cu, 3.62% Zn, and 39.34 g/tonne Ag.	66RF 0178	Galena	II	1.63	21.34	23.27	53.76	13.09	14.28	32.98	1.090	2.519	
				1.640	21.39	23.27	53.70	13.04	14.19	32.74	1.088	2.510	
	66RF 0181	Galena	II	1.54	22.66	22.66	53.14	14.71	14.71	34.51	1.000	2.345	
				1.549	22.71	22.66	53.08	14.65	14.62	34.26	0.998	2.337	
G) COBALT-SUDBURY AREA													
1) TIMAGAMI COPPERFIELDS copper mine													
46°57'50" 80°02'12" 41I/16 Phyllis Tp. On Timagami Island. 88 km NE of Sudbury, Ontario.	61RF 0049	Pyrite (U)	GSC	1.547	22.17	23.08	53.20	14.33	14.92	34.39	1.041	2.400	Low lead - Questionable
				1.548	22.22	23.09	53.14	14.35	14.92	34.32	1.039	2.391	
Chalcopyrite lenses and veins, with minor pyrite, sphalerite, millerite and gersdorffite at contact between Archean rhyolite breccia and massive rhyolite (Colvine, 1974). Total production was 609 941 tonnes of 5.7% Cu, 6.73 g/tonne Ag and 0.35 g/tonne Au.	61RF 0048	Pyrite (U)	GSC	1.387	23.71	21.48	53.42	17.09	15.49	38.51	0.906	2.253	Low lead - Questionable
				1.388	23.77	21.49	53.36	17.12	15.49	38.44	0.904	2.245	
2) GENEVA LAKE lead-zinc mine (past producer) Irvington Mining Co.													
46°47'30" 81°31'12" 41I/13 Hess Tp. 51 km NW of Sudbury, Ontario.	65RF 0002	Galena	II	1.575	21.69	23.49	53.25	13.77	14.91	33.81	1.083	2.455	
				1.585	21.74	23.49	53.19	13.72	14.83	33.56	1.081	2.447	
Thin tabular sphalerite-galena-pyrite-chalcopyrite deposits follow westerly-striking banding in amphibolite. Ore minerals are intergrown with metamorphic minerals. Silver content of ore was low. Similar deposits occur 13 km to the west in Moncreif and Craig townships and sulphide occurrences are found in the intervening area; all may be along the same geological unit, and all may be metamorphosed.	65RF 0001	Galena	II	1.558	22.02	23.34	53.08	14.13	14.98	34.07	1.060	2.411	
				1.568	22.07	23.34	53.02	14.08	14.8[illegible]	33.82	1.058	2.402	
	65RF 0002	Galena	GSC	1.595	21.75	23.50	53.15	13.64	14.73	33.32	1.080	2.444	
				1.602	21.79	23.53	53.07	13.60	14.69	33.12	1.080	2.435	
	65RF 0001	Galena	GSC	1.562	22.04	23.33	53.07	14.11	14.94	33.98	1.059	2.408	
				1.569	22.08	23.36	59.99	14.07	14.89	33.77	1.058	2.399	
Total production plus reserves are 176 309 tonnes of 9.7% Zn, 3.2% Pb, 2.05 g/tonne Au and 5.65 g/tonne Ag (Shklanka, 1969).													
3) STRALAK lead-zinc prospect													
46°48'12" 81°41'12" 41I/13 Moncreif Tp. and Craig Tp. 64 km NW of Sudbury, Ontario.	65RF 0005	Galena	II	1.590	21.64	23.48	53.29	13.61	14.77	33.52	1.085	2.463	
				1.600	21.69	23.48	53.23	13.56	14.68	33.27	1.083	2.454	
Sphalerite-galena-pyrite-pyrrhotite occurrences follow contact between steeply dipping metavolcanic and metasedimentary rocks, near a granite contact to the north. Sulphides intergrown with epidote and hornblende suggest that the deposits were pre-metamorphic.	65RF 0004	Galena	II	1.573	21.65	23.39	53.39	13.76	14.87	33.94	1.080	2.466	
				1.583	21.70	23.39	53.33	13.71	14.78	33.70	1.078	2.458	
	65RF 0005	Galena	GSC	1.593	21.64	23.42	53.35	13.58	14.70	33.49	0.924	2.465	
				1.600	21.68	23.44	53.27	13.55	14.65	33.29	1.081	2.457	
Reserves (1952) are estimated at 330 000 tonnes with average grade of 3.18% Zn, .32% Cu and 19.2 g/tonne Ag (Shklanka, 1969).	65RF 0004	Galena	GSC	1.587	21.73	23.43	53.26	13.69	14.76	33.56	1.078	2.451	
				1.594	21.78	23.45	53.18	13.66	14.71	33.36	1.077	2.442	

Table A.2

Pyritic stratiform sulphide deposits with low copper-zinc contents in Archean strata

a) sulphide iron formation type

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
A) CHIBOUGAMAU AREA													
1) PITCHER MOBI sulphide occurrence.													
49°57' 75°27' 32G/14 Guettard Tp.	63RF 0653	Pyrite	II	1.492	23.31	22.45	52.74	15.62	15.05	35.35	0.963	2.263	
77 km W of Chibougamau, Quebec.		(U)		1.501	23.36	22.45	52.68	15.56	14.96	35.09	0.961	2.255	
Pyrite, minor pyrrhotite and traces of chalcopyrite and sphalerite occur in massive layers, thin bands, disseminations and nodules in graphitic greywacke and argillite and in carbonate rock.	63RF 0649	Pyrite	II	1.274	25.57	20.73	52.42	20.00	16.21	41.00	0.811	2.050	
		(L)		1.282	25.63	20.73	52.36	19.92	16.11	40.70	0.809	2.043	
	63RF 0649	Pyrite	II	1.516	22.91	22.71	52.86	15.11	14.98	34.87	0.991	2.307	
		(U)		1.525	22.96	22.71	52.80	15.05	14.89	34.62	0.989	2.300	
2) DORE LAKE pyrite occurrence.													
49°54'00" 74°19'20" 32G/16 MacKenzie Tp.	63RF 0657	Pyrite	II	1.604	21.87	23.11	53.41	13.63	14.41	33.30	1.057	2.442	
3.2 km S of Chibougamau, Quebec.		(U)		1.614	21.92	23.12	53.35	13.58	14.32	33.06	1.055	2.434	
Laminated pyrite and chloritoid occur in a thin band along the north side of a siderite zone.													
B) KIRKLAND LAKE AREA													
1) ROCHE base metal prospect.													
48°19'00" 79°39'45" 32D/4 Ben Nevis Tp.	63RF 0213	Galena	GSC	1.619	21.45	23.36	53.57	13.24	14.42	33.08	1.089	2.497	
32 km NE of Kirkland Lake, Ontario.				1.620	21.50	23.38	53.51	13.27	14.43	33.02	1.087	2.489	
Sphalerite-pyrite-galena in fractures in rhyolite breccia near dacite.													
2) ADAMS iron mine. (Producer) Dominion Foundaries and Steel Co.													
48°04'52" 79°54'58" 32D/4 Boston Tp.	64RF 0095	Galena	II	1.540	22.45	23.25	52.75	14.58	15.10	34.25	1.036	2.350	
11 km SE of Kirkland Lake, Ontario.				1.549	22.50	23.25	52.69	14.52	15.01	34.01	1.033	2.342	
An occurrence of galena in black argillite along the south margin of the chert-magnetite iron formation contains pyrite and pyrrhotite in bands and fine disseminations and abundant small to very large nodules. Veins containing coarse galena and sphalerite cut the pyritic formation. Sulphides including chalcopyrite also occur within the chert-magnetite iron formation. Felsic tuff and alkaline basalts are predominant in the immediate area. From 1964 to 1972 29 460 000 tonnes of ore, yielding 7 394 000 tonnes of 64.5% Fe pellets were produced.													
C) COBALT SUDBURY AREA													
1) TIMAGAMI MINE ROAD pyrite occurrence.													
46°57'40" 80°00'00" 41I/16 Phyllis Tp.	61RF 0388	Pyrite	GSC	1.609	21.60	23.41	53.38	13.43	14.55	33.18	1.084	2.471	
480 m E of road end. About 80 km NE of Sudbury, Ontario.		(R)		1.610	21.65	23.43	53.32	13.45	14.55	33.11	1.082	2.463	
				1.599	21.59	23.37	53.44	13.50	14.62	33.42	1.082	2.475	
Pyrite in sheared andesite.				1.600	21.64	23.38	53.38	13.52	14.61	33.36	1.081	2.467	
				1.598	21.62	23.41	53.37	13.53	14.65	33.40	1.083	2.468	
				1.599	21.65	23.43	53.31	13.55	14.65	33.33	1.081	2.460	
				1.601	21.63	23.42	53.35	13.51	14.63	33.33	1.083	2.467	
				1.602	21.69	23.43	53.28	13.53	14.63	33.26	1.081	2.458	
	61RF 0388	Pyrite	GSC	1.500	23.37	22.91	52.22	15.57	15.27	34.80	0.980	2.235	
		(L)		1.501	23.42	22.92	52.15	15.60	15.27	34.75	0.979	2.227	
				1.501	23.39	22.88	52.22	15.58	15.24	34.79	0.978	2.232	
				1.502	23.44	22.90	52.16	15.61	15.24	34.72	0.977	2.225	
				1.506	23.52	22.87	52.10	15.61	15.18	34.59	0.972	2.215	
				1.507	23.57	22.88	52.04	15.64	15.18	34.53	0.971	2.207	
	61RF 0388	Pyrite	GSC	1.577	22.14	23.27	53.01	14.04	14.76	33.62	1.051	2.395	
		(U)		1.578	22.19	23.28	52.95	14.06	14.75	33.55	1.049	2.386	
				1.545	22.61	23.15	52.69	14.63	14.98	34.10	1.024	2.331	
				1.546	22.66	23.16	52.63	14.66	14.98	34.04	1.022	2.322	
				1.569	22.32	23.24	52.87	14.23	14.81	33.70	1.041	2.368	
				1.570	22.37	23.25	52.81	14.25	14.81	33.63	1.040	2.361	
				1.553	22.40	23.17	52.87	14.42	14.92	34.04	1.034	2.360	
				1.554	22.45	23.19	52.81	14.45	14.92	33.98	1.033	2.352	
				1.573	21.93	23.29	53.20	13.94	14.80	33.82	1.062	2.426	
				1.574	21.98	23.30	53.13	13.96	14.80	33.76	1.060	2.418	
				1.564	22.42	23.18	52.83	14.33	14.83	33.78	1.034	2.357	
				1.565	22.47	23.20	52.77	14.36	14.82	33.71	1.032	2.348	
				1.576	22.13	23.26	53.04	14.05	14.76	33.66	1.051	2.396	
				1.577	22.18	23.27	52.97	14.06	14.76	33.59	1.049	2.388	

Table A.2 a) sulphide iron formation type (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
2) NORTHLAND pyrite, copper prospect.													
47°10'20" 79°44'10" 31M/4 Best Tp. 13 km N of Timagami, Ontario.	63RF 0210	Pyrite (U)	II	1.557 1.565	22.06 22.09	23.38 23.36	53.10 52.99	14.17 14.11	14.95 14.86	34.10 33.85	1.055 1.053	2.407 2.399	
Massive pyrite deposit in volcanic rocks in contact with graphite.													
3) MARSHAY TWP. zinc-lead prospect Zenmac Mines Ltd.													
47°09'25" 81°27'00" 41P/3 Marshay Tp. 81.5 km NNW of Sudbury, Ontario.	63RF 0011	Galena	II	1.521 1.530	22.25 22.30	23.27 23.27	52.96 52.90	14.63 14.57	15.30 15.21	34.82 34.57	1.046 1.044	2.380 2.372	
Pyrrhotite, pyrite and locally sphalerite and galena occur in a band of cherty tuff explored in pits and drill holes north of Zinc Lake. Sulphides appear to be an integral part of the metamorphic rock but galena also occurs along fractures.													
The deposit is in the form of a "shoot" averaging 150 km in length and 119 m in width. Average grades are 5.02% Zn, 1.91% Pb and 10 g/tonne Ag (Shklanka, 1969).													
4) BOTHA TWP. zinc-lead occurrence.													
46°56'20" 81°16'25" 41I/13 Botha Tp. Venetian Lake, 34.5 km NNW of Sudbury, Ontario.	65RF 0010	Galena	II	1.474 1.483	23.11 23.16	22.94 22.94	52.47 52.41	15.68 15.62	15.56 15.47	35.60 35.34	0.993 0.991	2.270 2.263	
Pyrite, sphalerite, chalcopyrite and galena are found in a narrow band of banded siliceous tuff in Archean volcanic rocks 120 m N of Venetian Lake. The occurrence was explored by a few small pits and short drillholes.	65RF 0010	Galena	II	1.483 1.490	23.14 23.18	22.93 22.96	52.45 52.37	15.60 15.54	15.46 15.37	35.37 35.11	0.991 0.990	2.267 2.259	
5) KITCHENER TWP. copper-zinc lead occurrence.													
46°49'05" 81°05'05" 41I/14 Kitchener Tp. 35 km N of Sudbury, Ontario.	65RF 0013	Galena	II	1.396 1.402	23.88 23.93	22.29 22.29	52.44 52.37	17.13 17.06	15.99 15.90	37.62 37.35	0.933 0.932	2.196 2.189	
Iron sulphides, chalcopyrite, sphalerite and galena occur in siliceous tuff near lean iron formation in pit 450 m SE of S arm of Bigwood Lake. Sulphides are intergrown with silicates in the metamorphic rock (Shklanka, 1969).													
D) TIMMINS AREA													
1) RUSH LAKE iron prospect Excelsior Mines Ltd.													
47°50' 82°12' 41P/16 Genoa Tp. 93 km SW of Timmins, Ontario.	64RF 0086	Galena	II	1.531 1.540	22.64 22.69	23.18 23.18	52.65 52.59	14.79 14.73	15.14 15.05	34.39 34.14	1.024 1.022	2.326 2.318	
Extensive iron formation contains chert-magnetite and sulphide rich phases. At this locality pyrrhotite is disseminated in dark cherty rock; pyrite, sphalerite, fine-grained galena and chalcopyrite occur in small lenses; coarse galena and other sulphides occur along fractures.													
Reserves (1952) were estimated at 44 918 tonnes having an average grade of 2.04% Pb and 4.02% Zn (Shklanka, 1969; C.M.H., 1972).													
2) PETER LAKE lead-zinc prospect.													
47°42'40" 82°42'25" 41P/15 Cunningham Tp. 133 km SW of Timmins, Ontario.	64RF 0087	Galena	II	1.497 1.506	22.84 22.89	23.09 23.09	52.58 52.51	15.26 15.20	15.42 15.33	35.12 34.87	1.011 1.009	2.302 2.294	
Prospect along chert-magnetite iron formation with associated sulphide-rich dark cherty and graphitic rocks; galena and sphalerite are in fractures.													
E) VAL D'OR AREA													
1) MARBRIDGE zinc-copper prospect.													
48°20'00" 78°12'00" 32D/3 Lamotte Tp. 41.5 km NW of Val d'Or, Quebec.	63RF 0022	Pyrite (L)	GSC	1.504 1.505	23.29 23.34	22.46 22.47	52.75 52.68	15.48 15.51	14.93 14.93	35.07 35.01	0.960 0.958	2.270 2.262	Low lead – Questionable
Pyrrhotite-pyrite-sphalerite-chalcopyrite in cherty tuff band in Archean volcanic rocks; near nickel mine (Clark, 1965). Total production was 702 900 tonnes of 2.28% Ni, 0.1% Cu.													
F) SAULT STE. MARIE AREA													
1) MAMMOUTH lead-zinc occurrence.													
48°01'40" 84°42'00" 42C/2 Tp. 29 R 14 6.5 km NE of Wawa, Ontario.	65RF 0043	Galena	II	1.547 1.556	21.91 21.96	23.55 23.55	53.00 52.93	14.16 14.11	15.22 15.13	34.26 34.01	1.075 1.073	2.419 2.411	
Coarse sphalerite, arsenopyrite, galena, quartz and carbonate in fractures in diorite within a sequence of acidic volcanic rocks stratigraphically underlying iron formation. Deposit is about 300 m stratigraphically beneath the iron formation.	65RF 0013	Galena	II	1.560 1.567	21.96 22.00	23.55 23.58	52.93 52.85	14.08 14.04	15.10 15.01	33.93 33.68	1.072 1.070	2.410 2.402	

b) vein type

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
G) TIMMINS AREA													
1) JAMESON TP. zinc vein occurrence.													
48°32'20" 81°35'36" 42A/12 Jameson Tp. 19 km WNW of Timmins, Ontario.	64RF 0227	Galena	II	1.606 1.616	21.48 21.53	23.35 23.36	53.56 53.50	13.37 13.32	14.54 14.45	33.35 33.11	1.087 1.085	2.493 2.485	
North-trending fracture zone in gabbro contains quartz, carbonate, pyrite and sphalerite.													
2) GODFREY TP. lead-zinc occurrence.													
48°30'30" 81°31'45" 42A/12 Godfrey Tp. 14.5 km WNW of Timmins, Ontario.	64RF 0220	Galena	II	1.514 1.523	22.63 22.68	23.15 23.15	52.70 52.64	14.95 14.89	15.29 15.20	34.81 34.56	1.023 1.021	2.329 2.321	
Sphalerite-galena-carbonate-quartz vein in Archean rhyolite.													
3) LITTLE NIGHTHAWK LAKE lead-zinc occurrence.													
48°09'23" 81°02'36" 42A/3 Cleaver Tp. 41.5 km SSE of Timmins, Ontario.	65RF 0591	Galena	II	1.495 1.504	23.05 23.10	23.10 23.10	52.36 52.30	15.42 15.36	15.45 15.36	35.02 34.77	1.002 1.000	2.272 2.264	
Galena-sphalerite-calcite vein in Archean rhyolite near Aphebian Gowganda Formation.													
H) KIRKLAND LAKE AREA													
1) BLACK TP. copper-lead occurrence.													
48°20' 80°22'40" 42A/8 Black Tp. 32 km NW of Kirkland Lake, Ontario.	63RF 0218	Galena	II	1.601 1.611	21.44 21.49	23.43 23.43	53.53 53.47	13.39 13.34	14.63 14.55	33.44 33.19	1.093 1.091	2.497 2.489	
Pyrite, chalcopyrite, and galena in quartz vein in Archean volcanics near Gowganda Formation.													
2) ST. PIERRE lead-zinc-silver-gold occurrence.													
48°11'25" 79°57'20" 32D/4 Morisette Tp. 6.4 km NE of Kirkland Lake, Ontario.	61RF 0219	Galena	GSC	1.589 1.590	21.59 21.64	23.31 23.32	53.31 53.44	13.59 13.61	14.67 14.67	33.67 33.61	1.080 1.078	2.478 2.470	
Sphalerite-galena-chalcocite-pyrite-quartz-carbonate veins in Archean mafic metavolcanic rock.													
3) WOLF LAKE zinc-lead prospect													
48°14'50" 80°11'40" 42A/1 Maisonville Tp. 16 km NW of Kirkland Lake, Ontario.	63RF 0232	Galena	GSC	1.544 1.545	22.47 22.52	23.16 23.17	52.83 52.76	14.55 14.58	14.99 15.00	34.21 34.15	1.030 1.029	2.351 2.343	
Sphalerite-pyrite-quartz-carbonate veins in Archean dacite.													
4) MATARROW lead-zinc mine (Past Producer) Jarrow Mines Ltd.													
47°55'00" 80°44'00" 41P/15 Yarrow Tp. 75 km SW of Kirkland Lake, Ontario.	61RF 1055	Galena	GSC	1.536 1.537	22.56 22.61	23.22 23.23	52.69 52.62	14.69 14.71	15.12 15.12	34.31 34.24	1.029 1.028	2.336 2.327	
Sphalerite-galena-pyrite-chalcopyrite veins associated with pyritic iron formation. The deposit produced 36 102 tonnes of 3.3% Pb, 1.44% Zn and 3.13 g/tonne Ag (Shklanka, 1969).													
5) DANE galena occurrence.													
48°03'30" 79°57'00" 32D/4 Boston Tp. 14.5 km SSE of Kirkland Lake, Ontario.	63RF 0130	Galena	GSC	1.535 1.536	22.48 22.53	23.18 23.20	52.80 52.74	14.64 14.67	15.10 15.10	34.39 34.33	1.031 1.030	2.349 2.341	
Galena and carbonate in fractures in diorite.													
6) LOWE lead-zinc deposit.													
48°03'00" 79°45'00" 32D/4 Boston Tp.	63RF 0155	Galena	GSC	1.528 1.529	22.48 22.53	23.17 23.18	52.83 52.76	14.71 14.73	15.17 15.16	34.58 34.51	1.031 1.029	2.350 2.342	
Sphalerite-galena-pyrite-quartz-carbonate vein in Archean mafic volcanic rock.													
7) SOLMES lead-zinc occurrence.													
48°19' 80°19' 42A/8 Black Tp. 27 km NW of Kirkland Lake, Ontario.	64RF 0091	Galena	II	1.522 1.531	22.70 22.75	23.15 23.15	52.63 52.57	14.91 14.86	15.21 15.12	34.58 34.33	1.020 1.018	2.319 2.311	Sample from: W. Savage
Galena-sphalerite-chalcopyrite-calcite-quartz veins in rhyolite (Shklanka, 1969).													
8) BENOIT TP. lead-zinc-copper occurrence.													
48°19'50" 80°12'00" 42A/4 Benoit Tp. 21 km NNW of Kirkland Lake, Ontario.	63RF 0199	Galena	II	1.494 1.503	23.01 23.06	22.87 22.87	52.62 52.56	15.40 15.34	15.31 15.22	35.22 34.97	0.994 0.992	2.287 2.279	
Quartz carbonate vein 25.4 cm thick, in Archean dacite and north-trending Matachewan (Kenoran) diabase dyke contains galena, sphalerite, chalcopyrite and pyrite.													

Table A.2 b) vein type (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
I) ROUYN-NORANDA AREA													
1) JOANNES TP. galena-drusy quartz occurrence.													
48°13'15" 78°40'58" 32D/2 Joannes Tp. 21 km E of Noranda, Quebec.	65RF 0733	Galena	II	1.548	22.06	23.26	53.13	14.25	15.03	34.32	1.054	2.408	
				1.558	22.11	23.26	53.07	14.20	14.94	34.07	1.052	2.400	
Northerly trending drusy quartz vein with carbonate, pyrite, chalcopyrite, and galena in Archean metasedimentary rocks in railway rock cut.													
2) QUEMONT vein.													
48°15'25" 79°00'30" 32D/3 Rouyn Tp. Noranda, Quebec.	63RF 0053	Galena	GSC	1.233	26.01	19.80	52.96	21.09	16.05	42.95	0.761	2.036	
				1.234	26.07	19.81	52.89	21.13	16.06	42.87	0.760	2.029	
A post-ore vein cutting South Horne Fault orebody. The vein contains calcite, marcasite, sphalerite and galena (Weeks, 1967).													
J) COBALT AREA													
1) FABRE TP. lead-copper occurrence.													
47°11'10" 79°21'30" 31M/3 Fabre Tp., Quebec. 32 km SE of Cobalt, Ontario.	65RF 0102	Galena	II	1.486	23.30	22.77	52.45	15.68	15.32	35.30	0.977	2.251	
				1.495	23.35	22.77	52.38	15.62	15.23	35.04	0.975	2.243	
Quartz-carbonate veins in diorite contain pyrite, sphalerite, chalcopyrite and galena. Occurrence is less than 2 miles from Grenville rocks (SP-2, 1967).													
2) LORRAINE copper-nickel mine; post-ore calcite-galena-silver vein.													
47°21'36" 78°56'35" 31M/6 Gaboury Tp., Quebec 75 km E of Cobalt, Ontario.	65RF 0186	Galena	II	1.274	26.53	20.42	51.78	20.82	16.03	40.64	0.770	1.952	
				1.282	26.59	20.42	51.71	20.74	15.93	40.35	0.768	1.945	
Several calcite-galena-marcasite-native silver veins transect both massive ore and meta-andesite and meta-diorite host rocks of an Archean nickel-copper deposit; the two inch veins are probably related to Aphebian rocks which outcrop in the area (Descarreaux, 1967).													
K) SAULT STE. MARIE AREA													
1) TRIBAG copper mine, Breton pipe													
47°05'20" 84°30'06" 41N/2 Tp. 28 About 64 km NW of Sault Ste. Marie, Ontario.	65RF 0060	Galena	II	1.401	23.98	22.23	52.39	17.12	15.87	37.39	0.927	2.185	
				1.410	24.03	22.23	52.33	17.05	15.77	37.12	0.925	2.177	
	65RF 0060	Galena	GSC	1.414	23.97	22.19	52.43	16.95	15.69	37.08	0.923	2.187	
				1.420	24.02	22.22	52.35	16.91	15.64	36.85	0.925	2.180	
Breccia zone in Kenoran granite, Archean greenstone, and Keweenawan diabase, cut by Keweenawan diabase. Breccia is cemented by quartz, carbonate, chalcopyrite, pyrite and muscovite with molybdenite and fluorite, rare galena and sphalerite. K-Ar dates on muscovite and whole rock diabase range from 860 to 1060 m.y. (Blecha, 1974).													
Total production of 817 207 tonnes of 1.64% Cu. Reserves are estimated to be 36 280 000 tonnes of 0.2% Cu.													
L) THUNDER BAY AREA													
1) PAYS PLAT GRAVEL RIVER ameythst, fluorite.													
48°53' 87°37' 42D/13 Tp. 87 128 km ENE of Thunder Bay, Ontario.	66RF 0310	Galena	GSC	1.168	25.07	18.87	54.89	21.46	16.16	46.99	0.753	2.189	
				1.174	25.15	18.90	54.78	21.41	16.09	46.65	0.752	2.179	
Fractures in Archean granite filled with ameythst, fluorite, calcite and minor galena; 12.8 km east and 5 miles northeast of extensive exposures of Sibley sedimentary rocks (Helikian) 3.2 km north and west of exposures of Gunflint sedimentary rocks (Aphebian).													

Table A.3

Sulphide deposits associated with ultramafic and anorthositic intrusive rocks in Archean terrain

a) Chibougamau type deposits

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
A) CHIBOUGAMAU AREA													
1) OPEMISKA copper mine (Perry Shaft) (Producer) Falconbridge Copper Ltd.													
49°46'50" 74°51'15" 32G/15 Levy Tp. 38 km WSW of Chibougamau, Quebec.	63RF 0622	Pyrite (L)	II	1.558 1.567	22.56 22.61	23.08 23.08	52.81 52.74	14.48 14.42	14.81 14.73	33.90 33.65	1.023 1.021	2.341 2.333	
Chalcopyrite, pyrite, magnetite and quartz occur in veins in gabbro phase of an ultra-basic complex intrusive into Archean strata. The deposit contains significant amounts of gold and silver, and minor molybdenite and uraninite (McMillan, 1972).	63RF 0614	Pyrite (U)	II	1.433 1.422	25.20 25.26	22.11 22.11	51.25 51.19	17.59 17.52	15.43 15.34	35.76 35.51	0.877 0.876	2.034 2.027	
	66RF 0579	Galena	II	1.51" 1.52"	23.62 23.67	22.86 22.86	52.01 51.95	15.60 15.58	15.14 15.05	34.44 34.19	0.968 0.966	2.202 2.195	
Total production plus reserves are 20 831 000 tonnes of 2.44% Cu, with approximately 0.6 g/tonne Au and 10 g/tonne Ag.													
2) COPPER RAND CHIBOUGAMAU copper mine (Producer) Patino Mining Co.													
49°53'00" 74°16'50" 32G/16 McKenzie Tp. 4.8 km E of Chibougamau, Quebec.	63RF 0624	Pyrite (R)	II	1.556 1.556	22.23 22.28	23.02 23.03	53.19 53.13	14.29 14.23	14.79 14.71	34.18 33.94	1.036 1.033	2.393 2.385	
Vein-like body of chalcopyrite-pyrite-pyrrhotite ore in a wide shear and alteration zone within anorthosite (Allard, 1976).													
Total production plus reserves of 11 078 100 tonnes of 1.95% Cu and 2.00 g/tonne Au.													
3) CAMPBELL CHIBOUGAMAU copper mine (Producer) Campbell Chibougamau Mines Ltd.													
49°52'03" 74°20'00" 32G/16 Obalski Tp. 4.8 km SSE of Chibougamau, Quebec.	63RF 0602	Pyrite (L)	II	1.544 1.553	22.72 22.77	22.90 22.90	52.84 52.78	14.71 14.66	14.83 14.74	34.22 33.98	1.008 1.006	2.326 2.318	
Veins follow shear zones in highly altered anorthosite-gabbro; contain chalcopyrite, pyrrhotite, pyrite, sphalerite and quartz (Duquette, 1970).	66RF 0573	Galena	II	1.52" 1.53"	22.80 22.85	22.83 22.83	52.85 52.79	15.00 14.94	15.02 14.93	34.77 37.69	1.001 0.999	2.318 2.310	
Production and reserves to 1979 are 8 338 700 tonnes grading 1.67% Cu.													
4) PORTAGE copper mine (Producer) Patino Mining Co.													
49°54'30" 74°11'00" 32G/16 Roy Tp. 11 km E of Chibougamau, Quebec.	63RF 0630	Chalco (L)	II	1.481 1.490	23.30 23.35	22.55 22.55	52.67 52.61	15.73 15.67	15.23 15.14	35.56 35.31	0.968 0.966	2.261 2.253	
Vein-like bodies of chalcopyrite-pyrite-pyrrhotite-quartz-siderite in highly altered, sheared meta-anorthosite (Duquette, 1970).	63RF 0630	Chalco (R)	II	1.486 1.495	23.57 23.62	22.39 22.39	52.55 52.49	15.86 15.80	15.07 14.98	35.36 35.11	0.950 0.948	2.230 2.222	
Total production plus reserves are 1 408 850 tonnes of 1.42% Cu and 2.08 g/tonne Au.	63RF 0631	Pyrite (U)	II	1.341 1.369	25.33 25.38	21.06 21.06	52.27 52.20	18.89 18.82	15.70 15.61	38.98 38.70	0.831 0.830	2.064 2.057	
	63RF 0631	Pyrite (R)	II	1.382 1.390	24.81 24.86	21.36 21.36	52.45 52.38	17.95 17.88	15.46 15.36	37.95 37.68	0.861 0.859	2.114 2.107	
	63RF 0631	Pyrite (L)	II	1.419 1.428	25.28 25.33	21.27 21.27	52.03 51.97	17.81 17.75	14.99 14.90	36.67 36.40	0.841 0.840	2.058 2.051	

b) nickel deposits

B) TIMAGAMI LAKE AREA													
1) O'CONNOR pyrite occurrence.													
47°02'19" 79°50'00" 31M/4 Strathcona Tp. 150 m SE of NE arm of Timagami Lake. 4.8 km SW of Timagami, Ontario.	61RF 0141	Pyrite (R)	GSC	1.536 1.537	22.21 22.26	22.99 23.01	53.26 53.20	14.46 14.48	14.97 14.97	34.68 34.61	1.035 1.033	2.400 2.390	Low lead
Pyrite, millerite, siegenite, chalcopyrite, at the base of a fractured metagabbro sill. The copper orebodies of the Copperfields mine are in rhyolite underlying the metadiorite sill.	61RF 0141	Pyrite (R)	GSC	1.549 1.550	22.17 22.22	23.10 23.11	53.18 53.12	14.31 14.33	14.92 14.91	34.33 34.27	1.042 1.040	2.399 2.390	
	61RF 0141	Pyrite (U)	GSC	1.504 1.505	22.45 22.50	22.84 22.86	53.20 53.14	14.93 14.95	15.19 15.18	35.38 35.30	1.018 1.016	2.370 2.362	Low lead
				1.542 1.543	22.52 22.57	22.95 22.96	52.99 52.92	14.61 14.63	14.88 14.88	34.36 34.30	1.019 1.017	2.353 2.345	
				1.553 1.554	22.26 22.31	23.01 23.02	53.18 53.11	14.33 14.36	14.81 14.82	34.24 34.18	1.034 1.032	2.389 2.381	
				1.512 1.513	22.60 22.65	22.89 22.91	52.99 52.93	14.95 14.97	15.14 15.14	35.05 34.98	1.013 1.011	2.345 2.337	
				1.533 1.534	22.38 22.43	22.92 22.94	53.16 53.10	14.60 14.62	14.95 14.95	34.67 34.61	1.024 1.023	2.375 2.367	

Table A.3 b) nickel deposits (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
				1.534	22.23	22.99	53.24	14.49	14.99	34.71	1.034	2.395	
				1.535	22.28	23.01	53.18	14.51	14.99	34.64	1.033	2.387	
				1.548	22.27	23.00	53.18	14.38	14.86	34.35	1.033	2.389	
				1.549	22.32	23.01	53.12	14.41	14.86	34.29	1.031	2.380	
				1.535	22.43	22.97	53.06	14.61	14.97	34.56	1.024	2.365	
				1.536	22.48	22.99	53.00	14.63	14.96	34.50	1.022	2.357	
	61RF 0141	Pyrite (L)	GSC	1.471	23.68	22.19	52.66	16.09	15.08	35.81	0.937	2.224	Low lead
				1.472	23.73	22.20	52.59	16.12	15.08	35.73	0.936	2.216	
C) VAL D'OR AREA													
1) MARBRIDGE nickel mine (Past Producer)													
48°20'00" 78°12'00" 32D/3 Lamotte Tp. 42 km NW of Val d'Or, Quebec.	63RF 0027	Galena	GSC	1.534	22.61	23.09	52.77	14.73	15.05	34.39	1.021	2.334	
				1.535	22.66	23.10	52.70	14.76	15.05	34.33	1.020	2.326	
Pyrrhotite, pentlandite, pyrite, millerite, and chalcopyrite in serpentinite near contact between ultramafic and tuffaceous rocks. The sample taken from a galena-sphalerite-marcasite-quartz vein within the mine.													

Table A.4

Gold deposits in Archean rocks

a) Gold deposits in Archean metasedimentary and metavolcanic rocks

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
A) KIRKLAND LAKE-NORANDA AREA													
1) KERR ADDISON gold mine (Producer)													
48°08'05" 79°34'49" 32D/4 McGarry Tp. 32 km E of Kirkland Lake, Ontario.	64RF 0415	Pyrite (R)	II	1.533	21.55	23.26	53.66	14.06	15.17	35.00	1.079	2.490	
				1.542	21.60	23.26	53.60	14.00	15.08	34.75	1.077	2.481	
Large orebodies, within a zone 900 m long and up to 180 m thick between steeply-dipping metavolcanic rocks and greywacke, consist of stockworks of thin quartz veins in green carbonate rock and pyritic zones in tuff, agglomerate and felsic to intermediate lava. There are some small, altered syenitic intrusive rocks.	64RF 0415	Pyrite (U)	II	1.638	21.70	23.41	53.25	13.25	14.29	32.51	1.079	2.454	
				1.645	21.75	23.41	53.19	13.20	14.21	32.27	1.076	2.446	
	64RF 0418	Galena (U)	II	1.591	21.66	23.34	53.41	13.61	14.67	33.57	1.078	2.466	
				1.601	21.71	23.34	53.35	13.56	14.58	33.33	1.075	2.458	
Total production plus reserves are 32 289 232 tonnes of 7.19 g/tonne Au (Ferguson et al., 1971).	64RF 0417	Galena (U)	II	1.582	21.82	23.29	53.31	13.79	14.72	33.70	1.067	2.443	
				1.592	21.87	23.29	53.25	13.74	14.63	33.45	1.065	2.435	
	64RF 0405	Pyrite (U)	II	1.514	22.98	22.76	52.74	15.18	15.03	34.83	0.990	2.295	
				1.523	23.03	22.76	52.68	15.12	14.94	34.58	0.988	2.287	
	64RF 0405	Pyrite (R)	II	1.510	22.11	23.01	53.38	14.64	15.24	35.35	1.041	2.414	
				1.519	22.16	23.01	53.31	14.59	15.15	35.09	1.039	2.406	
	64RF 0405	Pyrite (L)	II	1.460	23.32	22.45	52.76	15.97	15.38	36.14	0.963	2.262	
				1.469	23.37	22.46	52.70	15.91	15.29	35.87	0.961	2.255	
2) NEW ROUYN MERGER gold mine (Past Producer)													
48°12'00" 78°52'28" 32D/2 Rouyn Tp. 11 km ESE of Noranda, Quebec.	65RF 0718	Galena (U)	II	1.588	21.57	23.37	53.47	13.58	14.72	33.67	1.083	2.479	
				1.598	21.62	23.37	53.41	13.53	14.63	33.43	1.081	2.471	
Mine is along Cadillac fault zone between metavolcanic and metasedimentary rocks. Pyritic samples on dump include finely laminated siliceous sediments and quartz-carbonate with pyrrhotite, chalcopyrite, arsenopyrite and rare galena (Wilson, 1962).													
Total production plus reserves are 119 724 tonnes of 18.5 g/tonne Au.													
B) TIMMINS AREA													
1) PAMOUR gold mine (Producer)													
48°31'33" 81°07'00" 42A/11 Whitney Tp. 16 km ENE of Timmins, Ontario.	64RF 0164	Galena	II	1.616	21.52	23.34	53.53	13.32	14.44	33.12	1.085	2.487	
				1.626	21.57	23.34	53.46	13.27	14.36	32.88	1.082	2.479	
Ore occurs in quartz veins in "Temiskaming" conglomerate and slate, and also in metavolcanic rocks unconformably underlying the sediments; veins and wall rocks contain disseminated pyrite, pyrrhotite, chalcopyrite, visible gold, and rarely sphalerite and galena (Ferguson et al., 1971).	64RF 0164	Galena	II	1.616	21.53	23.37	53.49	13.32	14.46	33.10	1.085	2.484	
				1.626	21.58	23.37	53.42	13.27	14.38	32.86	1.083	2.476	
Total production and reserves are 21 054 158 tonnes of 2.82 g/tonne Au.													

Table A.4 a) Gold deposits in Archean metasedimentary and metavolcanic rocks (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
2) SMITH-THORNE gold prospect													
47°57'20" 82°19'00" 41O/16 Horwood Tp. 91 km SW of Timmins, Ontario.	64RF 0031	Galena	II	1.602 1.612	21.48 21.53	23.37 23.39	53.55 53.49	13.41 13.36	14.59 14.50	33.43 33.18	1.088 1.086	2.493 2.485	
Quartz vein up to six feet wide dips 45°S in mafic volcanic rocks cut by quartz-feldspar porphyry bodies. Quartz contains pyrite, pyrrhotite, arsenopyrite, chalcopyrite, galena, sphalerite, tourmaline, calcite and gold.													
The occurrence contains 6034 tonnes of 8.9 g/tonne Au, and 1.56 g/tonne Ag.													
3) McINTYRE gold mine (Producer)													
48°28'48" 81°18'09" 42A/6 Tisdale Tp. 1.6 km E of Timmins, Ontario.	64RF 0498	Pyrite (R)	II	1.547 1.556	21.61 21.66	23.23 23.23	53.62 53.55	13.97 13.91	15.02 14.93	34.66 34.41	1.075 1.073	2.481 2.473	
Nodular pyrite in graphitic schist. Location in mine unknown. For further information see Carter, 1962.	64RF 0498	Pyrite (L)	II	1.501 1.510	22.05 22.10	23.04 23.04	53.41 53.35	14.69 14.63	15.35 15.26	35.58 35.32	1.045 1.043	2.422 2.414	
Total production plus reserves are 34 996 629 tonnes of 7.12 g/tonne Au, 7.13 g/tonne Ag.													
4) AUNOR gold mine (Producer)													
48°26'31" 81°17'00" 42A/6 Deloro Tp. 5.6 km SE of Timmins, Ontario.	64RF 0194	Pyrite (R)	II	1.533 1.542	22.49 22.54	22.84 22.84	53.14 53.08	14.67 14.61	14.90 14.81	34.66 34.41	1.016 1.014	2.363 2.355	
Ore occurs in a zone of altered mafic volcanic rocks and consists of quartz vein material, talc-chlorite schist and ankerite-rich rock, all containing pyrite; tourmaline and scheelite are also present in quartz veins; pyrrhotite and chalcopyrite also occur (Ferguson et al., 1971).	64RF 0194	Pyrite (L)	II	1.454 1.463	23.90 23.95	22.30 22.30	52.35 52.28	16.44 16.37	15.34 15.25	36.00 35.74	0.933 0.931	2.190 2.183	
Total production plus reserves are 7 173 550 tonnes of 8.14 g/tonne Au.													
5) DELNITE gold mine (Past Producer)													
48°26'15" 81°18'02" 42A/6 Deloro Tp. 4.8 km SE of Timmins, Ontario.	64RF 0168	Pyrite (L)	II	1.523 1.532	23.01 23.06	23.00 23.00	52.46 52.40	15.11 15.05	15.10 15.01	34.45 34.20	1.000 1.000	2.280 2.272	
Ore occurs in quartz veins with tourmaline, pyrite, pyrrhotite, minor chalcopyrite and native gold, and also in altered mafic volcanic wall rocks which are sheared, carbonatized, sericitized, silicified and rich in sulphides.													
Production to 1964 was 3 491 125 tonnes containing 2 577 131 Au and 205 584 Ag. Reserves (1964) were estimated at 104 144 tonnes having an average grade of 7.7 g/tonne Au (Ferguson et al., 1971).													
6) PAYMASTER gold mine (Past Producer)													
48°27'24" 81°15'56" 42A/6 Tisdale Tp. 4.8 km ESE of Timmins, Ontario.	64RF 0310	Pyrite (R)	II	1.490 1.499	22.44 22.45	22.79 22.80	53.31 53.25	15.06 15.00	15.30 15.20	35.78 35.52	1.016 1.013	2.376 2.368	
Ore occurs predominantly in sulphide-rich zones in mafic metavolcanic rocks adjacent to carbonate-rich rock; vein quartz is minor. Sulphides are pyrite, pyrrhotite and chalcopyrite (Ferguson et al., 1971).	64RF 0310	Pyrite (L)	II	1.340 1.348	24.38 24.43	21.85 21.85	52.45 52.38	18.19 18.12	16.31 16.21	39.14 38.86	0.896 0.894	2.151 2.144	
Total production plus reserves are 4 755 148 tonnes of 5.7 g/tonne Au.													
7) DOME gold mine, 1300 foot level													
48°27'46" 81°14'40" 42A/6 Tisdale Tp. 6.4 km ESE of Timmins, Ontario.	64RF 0366	Pyrite (U)	II	1.440 1.449	24.33 24.38	22.13 22.13	52.10 52.04	16.90 16.83	15.37 15.28	36.18 35.92	0.910 0.908	2.141 2.135	
Ore occurs as veins in altered "dacite", altered porphyry, conglomerate and slate, as ankerite-quartz veins, and as quartz-tourmaline veins in altered volcanic rocks. Pyrite is present in all ores (Fryer et al., 1979).													
Total production plus reserves are 33 972 592 tonnes of 7.2 g/tonne Au.													
8) BROULAN REEF gold mine (Past Producer)													
48°30'51" 81°10'28" 42A/11 Whitney Tp. About 11 km NE of Timmins, Ontario.	64RF 0320	Galena	II	1.306 1.314	24.84 24.90	21.26 21.26	52.59 52.53	19.02 18.95	16.28 16.18	40.27 39.98	0.856 0.854	2.117 2.110	
Ore occurs in steep and flat veins in schistose altered metavolcanic rocks and in "Temiskaming" conglomerate and slate that unconformably overlie the volcanics. Veins contain pyrite-pyrrhotite, chalcopyrite, arsenopyrite and, locally, sphalerite and galena.													
Total production was 1 944 609 tonnes of 5.98 g/tonne Au (Riddell, 1968).													

Table A.4 a) Gold deposits in Archean metasedimentary and metavolcanic rocks (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{205}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
C) TIMAGAMI AREA													
1) LITTLE DAN gold-arsenic prospect													
47°05'30" 79°47'46" 31M/4 Strathy Tp.	61RF 0190	Pyrite	GSC	1.596	21.76	23.24	53.40	13.64	14.56	33.46	1.068	2.454	Low lead –
About 3.2 km N of Timagami, Ontario.		(U)		1.597	21.81	23.26	53.34	13.66	14.56	33.39	1.066	2.446	Questionable
Pyrite with chalcopyrite-arsenopyrite-quartz vein in sheared greenstone (Sinclair et al., 1939).	61RF 0183	Pyrite	GSC	1.556	22.26	23.13	53.05	14.31	14.87	34.09	1.039	2.383	
		(U)		1.557	22.31	23.14	52.98	14.33	14.86	34.03	1.037	2.375	
Total reserves are 544 200 tonnes of 5.39 g/tonne Au.	61RF 0183	Pyrite	GSC	1.562	22.28	23.17	52.99	14.27	14.83	33.93	1.040	2.378	
		(U)		1.563	22.33	23.18	52.92	14.29	14.83	33.86	1.038	2.370	
2) HERMISTON-McCAULEY gold prospect													
47°06'04" 79°49'48" 31M/4 Strathy Tp.	66RF 0846	Galena	II	1.583	21.84	23.09	53.49	13.82	14.61	33.85	1.057	2.449	
22 miles SSW of Cobalt, Ontario.				1.593	21.89	23.09	53.43	13.77	14.52	33.60	1.055	2.441	
About 3 miles NW of Timagami, Ontario.													
Quartz veins with pyrite and galena in sheared, carbonatized sericitized and pyritized quartz diorite that intrudes felsic volcanics (Archean) and is intruded by greenstone, lamprophyre, and porphyry dykes (Sinclair et al., 1939).													
Reserves are 8161 tonnes of 12.9 g/tonne Au.													
D) SAULT STE. MARIE AREA													
1) MICHIPICOTEN area gold occurrence													
47°53'45" 84°47'25" 41O/15 Tp. 30 R 22	65RF 0037	Galena	II	1.588	21.58	23.41	53.43	13.59	14.74	33.65	1.085	2.476	
11 km S of Wawa, Ontario.				1.598	21.63	23.41	53.36	13.54	14.65	33.40	1.083	2.468	
Gold-quartz vein with abundant disseminated galena in volcanic rocks.													
E) VAL D'OR AREA													
1) VAUQUELIN TP. galena occurrence													
48°02' 77°18' 32C/3 Vauquelin Tp.	63RF 0168	Galena	II	1.586	21.66	23.48	53.27	13.66	14.80	33.59	1.084	2.459	
38 km E of Val d'Or, Quebec.				1.596	21.71	23.48	53.21	13.60	14.72	33.34	1.082	2.451	
Sample of quartz with galena donated by prospector from showing said to contain gold.													
2) SURIMAU TP. copper-zinc-nickel-molybdenum occurrence													
48°08'48" 78°20'00" 32D/1 Surimau Tp.	65RF 0330	Galena	II	1.553	22.70	22.86	52.89	14.65	14.75	34.12	1.007	2.330	
53 km ESE of Noranda, Quebec.				1.563	22.75	22.86	52.83	14.59	14.66	33.87	1.005	2.322	
Chalcopyrite, sphalerite, pyrite and trace of galena in veins cutting quartz-feldspar schist (Pontiac schists) adjoined to south by amphibolite schist that contains nickeliferous pyrrhotite, and chalcopyrite and is cut by a small pegmatite containing pyrrhotite and molybdenite.													
F) CHIBOUGAMAU AREA													
1) CHIBOUGAMAU EXPLORERS gold mine (Past Producer)													
49°30' 74°27' 32F/8 La Dauversiere Tp.	66RF 0843	Galena	II	1.373	23.76	22.35	52.62	17.34	16.31	38.34	0.941	2.210	
46 km S of Chibougamau, Quebec.				1.383	23.81	22.35	52.46	17.27	16.21	38.06	0.939	2.202	
Gold-quartz veins in Archean metavolcanic rocks that are relatively highly metamorphosed and within a few kilometres of Grenville Province gneisses (Duquette, 1970).													
Total reserves plus production are 3 083 388 tonnes of 6.72 g/tonne Au, 0.77 g/tonne Ag, and 0.48% Cu.													
b) Gold deposits associated with Archean intrusive rocks													
G) ROUYN-NORANDA AREA													
1) CHADBOURNE gold deposit													
48°14'50" 79°01'50" 32D/3 Rouyn Tp.	63RF 0539	Pyrite	II	1.621	21.79	23.36	53.23	13.44	14.41	32.84	1.072	2.443	
Noranda, Quebec.		(L)		1.631	21.84	23.36	53.17	13.39	14.33	32.60	1.070	2.435	
Carbonated, pyritic, brecciated felsic and mafic metavolcanic rocks are cut by syenite porphyry dykes and adjacent quartz diorite body.	63RF 0539	Pyrite	II	1.591	21.78	23.33	53.30	13.69	14.66	33.50	1.071	2.447	
		(R)		1.601	21.83	23.33	53.24	13.64	14.58	33.26	1.069	2.439	
Reserves are 997 700 tonnes with an average grade of 2.83 g/tonne Au.													
2) NEW MARLON gold mine (Past Producer)													
48°15'19" 79°02'10" 32D/3 Rouyn Tp.	64RF 0402	Pyrite	II	1.590	21.59	23.26	53.56	13.58	14.63	33.69	1.077	2.481	
3.2 km NW of Noranda, Quebec.		(U)		1.600	21.64	23.26	53.50	13.53	14.54	33.44	1.075	2.472	
Gold-bearing quartz-tourmaline-carbonate veins occur in highly altered diorite marginal to the Powell "granite" body.													

Table A.4 b) Gold deposits associated with Archean intrusive rocks (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
Production in 1946-47 was 98 174 tonnes containing 5.6 g/tonne Au (SP-2, 1967).													
3) RAINVILLE gold prospect													
48°18'00" 79°15'00" 32D/3 Duprat Tp. About 16 km NW of Noranda, Quebec.	63RF 0543	Galena	GSC	1.561 1.562	21.72 21.77	23.30 23.31	53.42 53.35	13.92 13.94	14.93 14.92	34.23 34.16	1.073 1.071	2.459 2.451	
Molybdenum-galena-chalcopyrite occur in quartz vein in syenite.													
4) BEATTIE gold mine (Past Producer)													
48°30'30" 79°14'05" 32D/11 Duparquet Tp. 32 km NNW of Noranda, Quebec.	63RF 0451	Pyrite (U)	II	1.547 1.556	23.42 23.47	22.73 22.73	52.31 52.24	15.14 15.08	14.69 14.61	33.81 33.57	0.971 0.969	2.234 2.226	
Large orebodies at the margin of a syenite porphyry which is intrusive into Archean tuff, volcanics and metasediments. Fine grained pyrite, arsenopyrite, magnetite and gold occurs in sericitized and brecciated tuff, volcanics, and porphyry and are associated with abundant quartz stringers. Late veins are reported to contain galena and fluorite (Davidson and Banfield, 1944).													
Total production was 9 644 800 tonnes of 4.01 g/tonne Au, 0.94 g/tonne Ag.													
5) DON ROUYN copper ore quarry													
48°15' 79°4' 32D/3 Rouyn Tp. About 6.4 km W of Noranda, Quebec.	64RF 062	Pyrite (L)	II	1.425 1.434	24.27 24.32	22.12 22.12	52.19 52.12	17.03 16.97	15.52 15.43	36.62 36.36	0.911 0.910	2.150 2.143	
Veinlets of quartz, chalcopyrite and molybdenite occur in altered, fractured, sheared portion of the Powell granite (Goldie, 1976).													
Reserves plus production are 91 334 300 tonnes of 0.15% Cu with minor gold content.													
H) VAL D'OR AREA													
1) SIGMA gold mine													
48°06'12" 77°44'33" 32C/4 Bourlamaque Tp. 1.6 km E of Val d'Or, Quebec.	64RF 0445	Pyrite (U)	II	1.459 1.468	23.17 23.22	22.11 22.11	53.26 53.20	15.88 15.82	15.15 15.06	36.50 36.24	0.954 0.952	2.299 2.291	
Deposit is a stock work of quartz-tourmaline veins in sheared altered pyritic diorite porphyry; rare chalcopyrite, visible gold and bismuth telluride occur in veins (Latulippe, 1976).													
Production plus reserves are 16 801 700 tonnes of 6 g/tonne Au and approximately 2 g/tonne Ag.													
2) SULLIVAN gold mine (Past Producer)													
48°07'40" 77°50'00" 32C/4 Dubuisson Tp. 3.2 km NW of Val d'Or, Quebec.	65RF 0715	Galena	II	1.599 1.609	21.50 21.55	23.34 23.34	53.56 53.50	13.45 13.39	14.60 14.51	33.50 33.25	1.086 1.083	2.491 2.483	
Quartz veins with coarse pyrite, tourmaline, visible gold, scheelite, and rare sphalerite, chalcopyrite and galena occur in granodiorite (Latullipe, 1976).													
The mine produced 4 865 200 tonnes of ore which contained 7.89 g/tonne Au and 1.85 g/tonne Ag.													
I) KIRKLAND LAKE AREA													
1) FLAVELLE TP. galena occurrence													
48°00' 80°31' 42A/2 Flavelle Tp. 38 km WSW of Kirkland Lake, Ontario.	64RF 0518	Galena (U)	II	1.605 1.615	21.57 21.62	23.38 23.39	53.44 53.38	13.44 13.39	14.57 14.48	33.30 33.05	1.084 1.082	2.478 2.469	
Galena, other sulphides, and quartz occur in fractures in mafic syenite.													
2) BUFFONTO galena occurrence													
48°28'30" 79°58'45" 32D/5 Garrison Tp. 35 km N of Kirkland Lake, Ontario.	64RF 0543	Galena (U)	II	1.585 1.595	21.83 21.88	23.30 23.30	53.28 53.22	13.77 13.72	14.70 14.61	33.62 33.37	1.067 1.065	2.441 2.432	
Veinlet contains galena and pyrite, in unaltered syenite, about 1 mile east of Buffonto gold prospect.													
3) ALMA TP. galena occurrence													
48°01' 80°37'30" 42A/2 Alma Tp. 40 km WSW of Kirkland Lake, Ontario.	64RF 0519	Galena (U)	II	1.583 1.593	21.85 21.90	23.31 23.32	53.25 53.19	13.80 13.75	14.73 14.64	33.64 33.40	1.067 1.065	2.437 2.429	
Galena, chalcopyrite, fluorite and reportedly gold and silver occur in small quartz vein in massive syenite.													

Table A.4 b) Gold deposits associated with Archean intrusive rocks (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
4) UPPER CANADA gold mine (Past Producer)													
48°08'27" 79°49'24" 32D/4 Gauthier Tp. 14 km E of Kirkland Lake, Ontario.	64RF 0422	Galena (U)	II	1.582 1.592	21.81 21.86	23.36 23.36	53.25 53.19	13.79 13.73	14.77 14.68	33.66 33.42	1.071 1.069	2.442 2.433	
Narrow tabular ore zones occur in sheared, altered pyritic trachyte; minor vein quartz with galena, sphalerite and chalcopyrite is common (Gordon et al., 1975).													
Total production is 1 267 544 tonnes of 7.5 g/tonne Au.													
5) HARKER gold prospect													
48°28' 79°38'30" 32D/5 Harker Tp. 40 km NNE of Kirkland Lake, Ontario.	64RF 0060	Galena	II	1.524 1.533	22.59 22.64	23.15 23.15	52.73 52.67	14.82 14.77	15.19 15.10	34.60 34.35	1.025 1.023	2.334 2.326	
Quartz-carbonate veins occur in metavolcanic rocks and thin layers of dark metasediments; porphyry breccia fragments were noted in mine dump; rocks are carbonatized.	64RF 0057	Galena	II	1.496 1.505	22.96 23.01	23.11 23.11	52.44 52.37	15.35 15.29	15.45 15.36	35.05 34.80	1.007 1.005	2.284 2.276	
J) TIMMINS AREA													
1) McINTYRE copper mine (in gold mine)													
48°29'00" 81°17'50" 42A/6 Tisdale Tp. 1.6 km E of Timmins, Ontario.	64RF 0231	Pyrite (L)	II	1.508 1.517	23.68 23.73	23.05 23.05	51.76 51.70	15.70 15.64	15.29 15.19	34.32 34.07	0.973 0.971	2.186 2.178	
Chalcopyrite, pyrite, tennantite are disseminated in fractured quartz porphyry.	64RF 0231	Pyrite (L)	II	1.556 1.565	23.86 23.91	23.01 23.01	51.58 51.51	15.33 15.27	14.79 14.70	33.15 32.91	0.964 0.962	2.162 2.154	
The copper reserves are 3.17 million tonnes of 0.74% copper (C.M.H., 1972).													
2) JEROME gold mine (Former Producer)													
47°37'30" 82°14'20" 41P/14 Osway Tp. 115 km SW of Timmins, Ontario.	64RF 0026	Galena	II	1.503 1.512	22.97 23.02	23.16 23.16	52.37 52.31	15.28 15.22	15.41 15.32	34.84 34.59	1.008 1.006	2.280 2.272	
The deposit consists of vein quartz, carbonate, and silicified carbonate rocks along a contact between greywacke and red syenite porphyry; locally intensely carbonatized, sericitized, and bleached. It contains pyrite and rare chalcopyrite, galena, sphalerite, molybdenite and visible gold (Moorhouse, 1950).													
Total production was 303 845 tonnes of 4.37 g/tonne Au.													
K) CHIBOUGAMAU AREA													
1) NORBEAU gold mine													
49°57'20" 74°17'25" 32G/16 Levy Tp. 26.4 km NE of Chibougamau, Quebec.	66RF 0845	Galena	II	1.553 1.563	21.52 21.57	23.30 23.30	53.63 53.57	13.88 13.83	15.03 14.94	34.60 34.35	1.083 1.081	2.492 2.484	
Two gold-quartz veins striking N-NNE plunging 50 E in carbonatized shears within Bourbeau differentiated mafic sill (Allard, 1976).													
Total production was 380 033 tonnes of 13.5 g/tonne Au and 1.7 g/tonne Ag.													
2) TACHE LAKE zinc-gold prospect (Berrigan Lake)													
49°56'30" 74°25' 32C/16 McKenzie Tp. 3.2 km NNW of Chibougamau, Quebec.	66RF 0844	Galena	II	1.533 1.543	21.47 21.52	23.27 23.27	53.73 53.67	14.03 13.98	15.21 15.12	35.12 34.86	1.084 1.082	2.503 2.494	
Sphalerite and pyrrhotite at the contact between serpentinite and Archean metasediments (Allard, 1976).													
Reserves are 345 895 tonnes of 7.49% Zn, 34.1 g/tonne Ag and 7.5 g/tonne Au.													

Table A.5

Mineral deposits in Aphebian rocks

a) Silver-cobalt-nickel vein deposits

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
A) COBALT AREA													
1) HORSESHOE LAKE													
47°33'40" 81°01'40" 41P/6 Leonard Tp. 22 km SSW of Gowganda, Ontario.	61RF 0862	Galena	GSC	1.532 1.533	22.67 22.72	23.11 23.12	52.69 52.62	14.79 14.82	15.08 15.08	34.38 34.32	1.019 1.018	2.325 2.316	
Native silver and cobalt sulpharsenide-bearing calcite veins associated with gabbro sill.													
2) HUDSON BAY silver mine (Past Producer) Rustex Mining Corp. Ltd.													
47°24'00" 79°41'00" 31M/4 Coleman Tp. Cobalt, Ontario.	61RF 1081	Galena	GSC	1.527 1.528	22.59 22.64	23.16 23.17	52.72 52.66	14.80 14.82	15.17 15.17	34.53 34.46	1.025 1.023	2.333 2.326	
Native silver, cobalt sulpharsenide-bearing calcite veins associated with an Aphebian gabbro sill.													
Total production to 1966 amounted to 2.5 million gm Ag and 256 kg Co. Reserves (1967) are reported at 9450 tonnes grading 380 g/tonne Ag (Sergiades, 1968).													
3) MALLARD LAKE native silver occurrence													
47°49'45" 79°39'24" 31M/13 Ingram Tp. 45 km SE of Kirkland Lake, Ontario.	63RF 0248	Galena	II	1.521 1.530	22.58 22.63	23.15 23.15	52.75 52.69	14.85 14.79	15.22 15.13	34.68 34.43	1.025 1.023	2.336 2.328	
Native silver - Co, Ni, sulpharsenides-galena-quartz-calcite vein in diabase that intrudes Gowganda Formation (Aphebian sedimentary rocks). This is the most northerly silver occurrence of the Cobalt camp.				1.519 1.528	22.59 22.64	23.22 23.22	52.67 52.61	14.87 14.81	15.29 15.20	34.67 34.42	1.028 1.026	2.332 2.324	
4) DEER HORN silver mine, Cross Lake (Past Producer) Deerhorne Mines Ltd.													
47°24'00" 79°38'40" 31M/4 Coleman Tp. SE of Cobalt, Ontario.	61RF 1218	Galena	GSC	1.525 1.526	22.54 22.59	23.18 23.19	52.76 52.69	14.78 14.80	15.20 15.20	34.61 34.53	1.028 1.027	2.341 2.333	
Calcite-silver-cobalt-galena veins occur in Keewatin greenstone which are overlain by Nipissing diabase.													
Total production to 1965 estimated at 357 689 100 gm Ag (Sergiades, 1968).													
5) LANGIS silver mine (Past Producer) Langis Silver and Cobalt Mining Co. Ltd.													
47°35'00" 79°34'00" 31M/5 Casey Tp., Ontario. At N end of Lake Timiskaming. About 19 km N of Cobalt, Ontario.	61RF 1011	Galena	GSC	1.517 1.518	22.71 22.76	23.10 23.11	52.67 52.61	14.97 14.99	15.23 15.23	34.72 34.65	1.017 1.015	2.319 2.311	
Galena with sphalerite, chalcopyrite, pyrrhotite and calcite in fractured Archean mafic metavolcanic and Cobalt Group sediments near a Nipissing diabase sill.													
Production to 1966 totalled 291 769 tonnes containing 262 446 380 g Ag and 162 512 kg Co. (Sergiades, 1968).													
6) MILLAR LAKE BASIN silver mine (Morrison) (Past Producer)													
47°39'00" 80°43'00" 41P/10 Nicol Tp., Ontario. About 80 km NW of Cobalt, Ontario.	61RF 0452	Galena	GSC	1.503 1.504	22.98 23.03	22.96 22.97	52.56 52.49	15.29 15.31	15.27 15.27	34.96 34.90	0.999 0.997	2.287 2.279	
Native silver-cobalt sulpharsenide-bearing calcite veins in Aphebian gabbro and granophyre (Nipissing diabase).													
Production to 1955 totalled 22 636 tonnes containing 20 137 628 g Ag and 9985 kg Co. (Sergiades, 1968).													

b) vein deposits in sediments

b) vein deposits in sediments

B) KIRKLAND LAKE AREA													
1) KENOGAMI gold occurrence													
48°07'25" 80°17'00" 42A/1 Bompas Tp. 19 km W of Kirkland Lake, Ontario.	64RF 0040	Galena	II	1.521 1.530	22.87 22.92	23.12 23.12	52.49 52.43	15.04 14.98	15.20 15.11	34.51 34.26	1.011 1.009	2.295 2.288	Sample from: R.M. Ginn
Pyrite-chalcopyrite-galena (rare) -carbonate-quartz veins in Gowganda Formation (Aphebian), sedimentary rocks.													

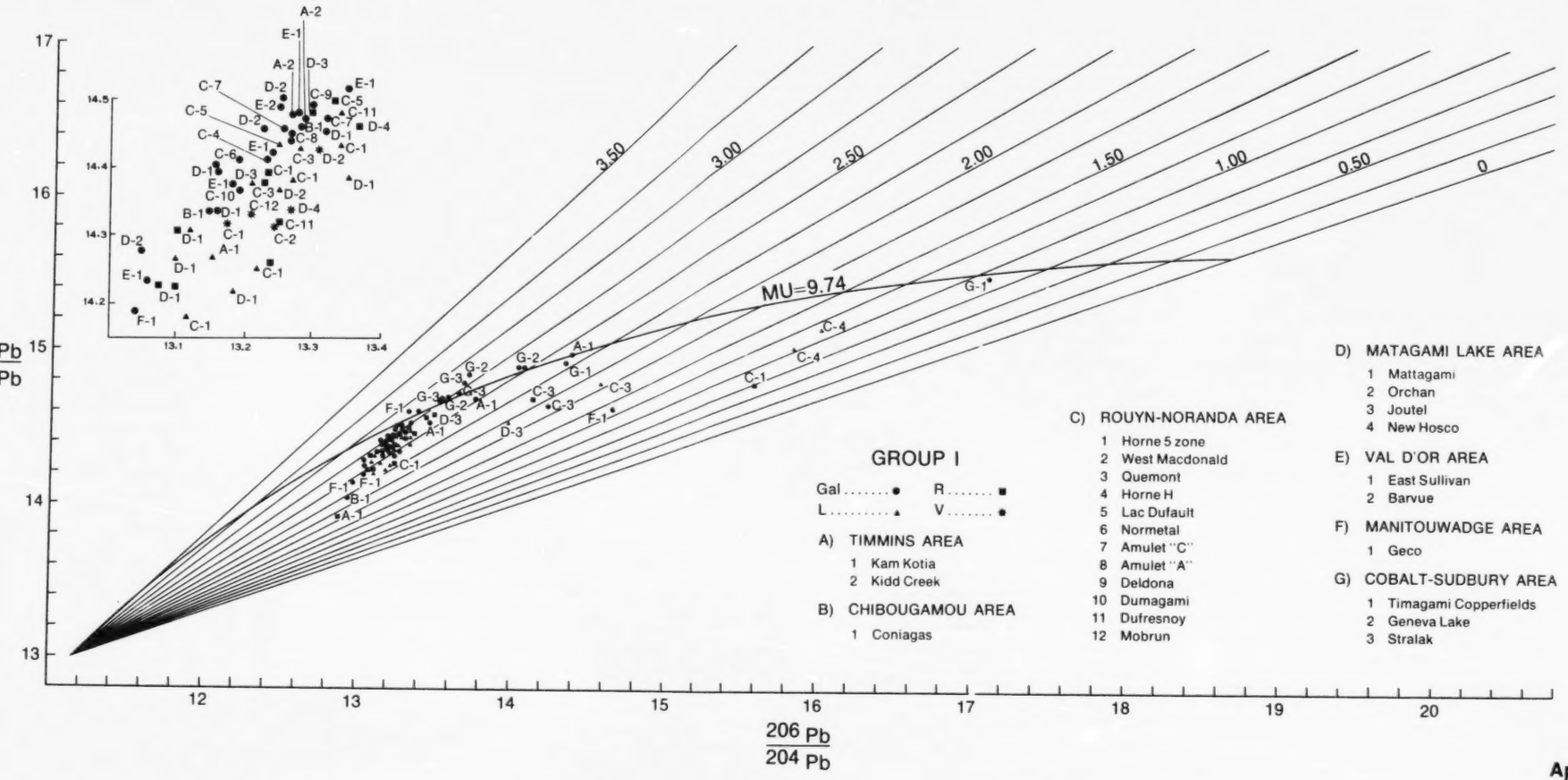
Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
C) CHIBOUGAMAU AREA													
1) MISTASSINI area lead-zinc occurrence													
50°30' 74° 32I	66RF 0592	Galena	II	1.403	24.77	22.37	51.46	17.69	15.98	36.76	0.903	2.078	
				1.413	24.83	22.37	51.40	17.62	15.88	36.49	0.901	2.071	
Galena and sphalerite in dolomite. Donated by Campbell Chibougamau Mines.	66RF 0591	Galena	II	1.513	22.77	22.82	52.90	15.08	15.11	35.03	1.002	2.323	
				1.523	22.82	22.82	52.84	15.02	15.02	34.77	1.000	2.315	
2) MISTASSINI POST lead-zinc occurrences													
50°26' 73°51'30" 32I/4 Duquet Tp. 67 km NNE of Chibougamau, Quebec.	66RF 0559	Galena	II	1.433	24.13	22.51	51.93	16.87	15.74	36.32	0.933	2.152	
				1.443	24.18	22.51	51.87	16.80	15.65	36.05	0.931	2.145	
Calcite, sphalerite, and galena in fractures in small folds near a fault zone within dolomite breccia.													
3) MUSCOCHO lead-zinc prospect													
50°32'30" 73°43'20" 32I/4 McQuat Tp. 69 km NE of Chibougamau, Quebec.	66RF 0590	Galena	II	1.463	23.46	22.49	52.59	16.07	15.40	36.02	0.959	2.242	
				1.473	23.51	22.49	52.53	16.01	15.31	35.76	0.957	2.234	
Galena, light-coloured sphalerite-pyrite-calcite in fractured dolomite of Mistassini Group (Aphebian). Donated by Campbell Chibougamau Mines.													
c) vein deposits associated with gabbro and gabbro sedimentary contacts													
D) THUNDER BAY AREA													
1) SHUNIAH silver mine (Past Producer)													
48°28'50" 89°12'30" 52A/6 McIntyre Tp. Northern part of Thunder Bay, Ontario	66RF 0340	Galena	GSC	1.155	28.34	19.26	51.26	24.54	16.68	44.37	0.680	1.809	
				1.156	28.40	19.27	51.19	24.57	16.67	44.28	0.678	1.802	
Vein zone cuts 15 m diabase capping, about 100 m of underlying Rove black argillite (Aphebian or possibly Helikian) and enters Archean volcanics and syenite. It contains argillite, galena, pyrite, chalcopyrite in calcite, quartz, and amethyst (Ingall, 1887).	66RF 0340	Galena	II	1.183	28.53	19.18	51.11	24.18	16.25	43.31	0.672	1.791	
				1.193	28.00	19.18	51.05	24.09	16.15	42.99	0.671	1.785	
E) COBALT AREA													
1) NEW DELHI gold prospect													
47°08'40" 80°21'30" 41P/1 Delhi Tp. 61 km SW of Cobalt, Ontario.	61RF 0211	Galena	GSC	1.499	23.36	22.91	52.23	15.58	15.28	34.83	0.981	2.236	
				1.500	23.41	22.92	52.16	15.61	15.28	34.78	0.979	2.228	
Gold-galena-chalcopyrite-calcite-quartz veins in Aphebian gabbro.	61RF 0211	Galena	GSC	1.492	23.34	22.92	52.25	15.64	15.36	35.01	0.982	2.239	
				1.493	23.39	22.93	52.18	15.67	15.36	34.95	0.980	2.231	
Reserves were estimated (1951) at 49 000 tonnes grading from 0.224 to 8.3 g/tonne Au, 52.8 to 116.8 g/tonne Ag, 6.35 to 12.17% Pb (Shklanka, 1969).	61RF 0211	Galena	GSC	1.486	23.31	22.90	52.30	15.68	15.41	35.19	0.982	2.243	
				1.487	23.36	22.91	52.24	15.71	15.41	35.13	0.981	2.236	
	61RF 0211	Galena	GSC	1.504	23.43	22.95	52.12	15.57	15.26	34.65	0.980	2.225	
				1.505	23.48	22.96	52.05	15.60	15.26	34.59	0.978	2.217	
	61RF 0212	Galena	GSC	1.494	23.32	22.94	52.25	15.60	15.35	34.97	0.984	2.241	
				1.495	23.37	22.95	52.18	15.63	15.35	34.91	0.982	2.233	
	61RF 0214	Galena	GSC	1.495	23.36	22.91	52.24	15.62	15.32	34.93	0.981	2.237	
				1.496	23.41	22.92	52.17	15.65	15.32	34.88	0.979	2.229	
F) SUDBURY AREA													
1) MIDAS gold prospect, Kukagami Lake													
46°43'00" 80°31'30" 41I/6 Rathbun Tp. 42 km NE of Sudbury, Ontario.	61RF 1281	Galena	GSC	1.481	24.01	22.87	51.64	16.21	15.44	34.87	0.953	2.151	
				1.482	24.06	22.88	51.57	16.24	15.44	34.80	0.951	2.143	
Gold-galena-chalcopyrite-bearing quartz vein in Aphebian gabbro.													
2) LEECH LAKE gold													
46°9'55" 81°30'3" 41I/3 Roosevelt Tp. About 56 km SW of Sudbury, Ontario.	61RF 1265	Pyrite (U)	GSC	1.410	24.87	21.96	51.77	17.63	15.57	36.71	0.883	2.082	Low lead - Questionable
				1.411	24.92	21.97	51.70	17.67	15.57	36.65	0.882	2.074	
Pyrite-arsenopyrite-quartz vein in quartzite of the Serpent Formation (Huronian) near a metagabbro dyke.													
G) SAULT STE. MARIE AREA													
1) LUCHAK copper deposit													
46°34'20" 83°54'00" 41J/5 Chesley additional Tp. 40 km E of Sault Ste. Marie, Ontario.	61RF 1241	Galena	GSC	1.427	24.23	22.59	51.74	16.99	15.84	36.27	0.932	2.135	
				1.428	24.29	22.61	51.68	17.01	15.83	36.19	0.931	2.128	
Quartz veins in Aphebian gabbro contain irregularly distributed blobs of galena-sphalerite-chalcopyrite.													

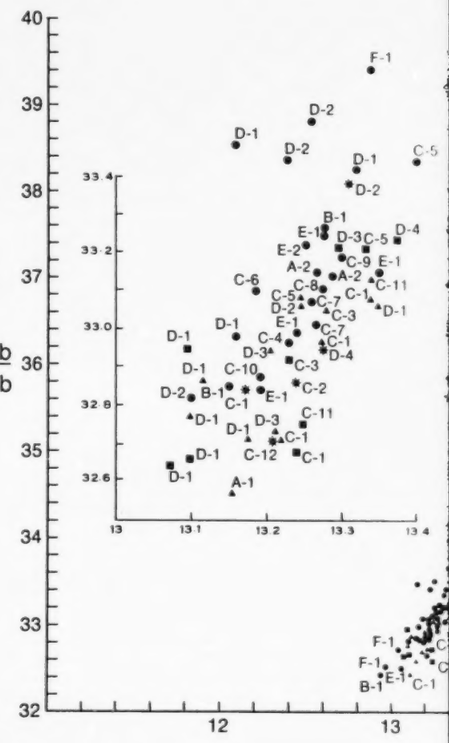
Table A.5 c) vein deposits associated with gabbro and gabbro sedimentary contacts (cont.)

Deposit	Sample No.	Mineral	Lab.	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Remarks
2) RANGERS LAKE lead-zinc prospect													
46°50' 83°40' 41J/13 Tp. 3H 64 km NE of Sault Ste. Marie, Ontario.	65RF 0014	Galena	II	1.370 1.378	24.65 24.71	21.90 21.90	52.08 52.02	17.99 17.93	15.99 15.89	38.02 37.75	0.888 0.886	2.113 2.105	
Veins containing sphalerite, galena, pyrite and calcite along fractures in a NW trending altered diabase dyke and at contact of dyke with granite.													
3) MONGOWIN nickel-copper prospect													
46°11'15" 81°45'15" 41I/4 Mongowin Tp., Ontario. About 10 km S of Espanola, Ontario.	61RF 1257	Pyrite	GSC	1.123 1.124	29.51 29.57	18.82 18.83	50.55 50.48	26.27 26.32	16.76 16.76	45.00 44.93	0.638 0.637	1.713 1.707	Low lead
Nickeliferous pyrrhotite, chalcopyrite and pyrite occur as sparse disseminations in the peridotitic portion of the Mongowin pluton. Muscovite at the south margin gave 1400 Ma (K-Ar) date.	61RF 1257	Pyrite	GSC	1.133 1.134	29.35 29.41	18.90 18.91	50.62 50.55	25.90 25.94	16.69 16.68	44.67 44.59	0.644 0.643	1.725 1.719	
d) endogenous deposits													
H) ELLIOT LAKE AREA													
1) STANROCK uranium exploration drillhole													
46°28'22" 82°33'56" 41J/2 Tp. 150 11 km NE of Elliot Lake, Ontario.	56RF 0004	Pyrite (L)	GSC	1.495 1.496	23.75 23.80	22.90 22.91	51.86 51.79	15.88 15.91	15.31 15.32	34.68 34.62	0.964 0.963	2.184 2.176	
Pyrite in conglomeratic greywacke, Bruce Formation, 500 m in hole 6; there may be a trace of associated sphalerite.	56RF 0004	Pyrite (U)	GSC	1.476 1.477	23.63 23.68	22.90 22.91	51.99 51.93	16.02 16.03	15.51 15.51	35.23 35.16	0.969 0.968	2.200 2.193	
2) SILVERMAQUE uranium exploration drillhole													
46°24'30" 82°30'15" 41J/2 Tp. 149 About 11 km E of Elliot Lake.	56RF 0009	Pyrrho (L)	GSC	1.485 1.486	23.72 23.77	22.75 22.76	52.05 51.98	15.98 16.00	15.32 15.32	35.05 34.98	0.959 0.958	2.194 2.187	
Pyrrhotite in siltstone at the base of the Pecors Formation at 689 m in hole 2, 12 m below diabase, trace of chalcopyrite.	56RF 0009	Pyrrho (U)	GSC	1.488 1.489	23.79 23.84	22.71 22.72	52.01 51.94	15.99 16.01	15.27 15.26	34.96 34.89	0.955 0.953	2.186 2.179	
I) LABRADOR TROUGH													
1) ROMANET LAKE AREA													
56°12' 67°57' 24B/4 Tp. 4852, 6.4 km W of Romanet Lake; 187 km NNW of Schefferville, Quebec.	66RF 0832	Galena	II	1.493 1.503	22.26 22.31	23.16 23.16	53.09 53.03	14.94 14.88	15.54 15.45	35.63 35.37	1.040 1.038	2.385 2.377	
2) CRAMOLET LAKE lead-zinc occurrence													
55°57' 67°46' 23O/13 Tp. 4652 141 km NNW of Schefferville, Quebec.	66RF 0833	Galena	II	1.423 1.433	22.46 22.51	22.95 22.95	53.17 53.11	15.82 15.76	16.16 16.06	37.44 37.17	1.022 1.020	2.367 2.359	
A lead-zinc occurrence in sedimentary rocks of the Attikamagen Formation.													
3) DODETTE LAKE AREA													
54°29'36" 66°00' 23J/5 67 km SE of Schefferville, Quebec.	66RF 0834	Galena	II	1.423 1.433	22.85 22.90	22.77 22.77	53.96 53.90	16.09 16.03	16.04 15.96	37.30 37.03	0.996 0.994	2.318 2.310	
4) PRUDHOMME NO. 1 sulphide deposit													
58°12' 69°49'33" 24K/4 Tp. 6044 427 km NNW of Schefferville, Quebec.	66RF 0835	Galena	II	1.413 1.423	22.84 22.89	22.56 22.56	53.19 53.13	16.20 16.14	16.00 15.90	37.72 37.44	0.988 0.986	2.329 2.321	
Massive sulfides occur at surface in argillaceous rock which is in contact with massive gabbro to the east and pillowed lava to the west (copper, zinc, sulphur, gold, silver). 4 303 700 tonnes of 2.04% Cu, 2.66% Zn, 32.5 g/tonne Ag.													
5) FREDRICKSON LAKE copper-zinc deposit													
55°05'14" 66°15'36" 23O/1 4158 Tp. 45 km NE of Schefferville, Quebec.	66RF 0836	Galena	II	1.413 1.423	23.02 23.07	22.59 22.59	52.98 52.92	16.33 16.27	16.02 15.92	37.57 37.30	0.981 0.979	2.301 2.293	
Tabular body of fine grained sphalerite with pyrrhotite, chalcopyrite, quartz, pyrite and galena in Aphebian slate (Menihek Formation) adjacent to gabbro sill which contains vein-like replacement bodies (Hogg, 1966).													
Reserves are 279 000 tonnes of 4.38% Zn, 0.77% Cu, 42 g/tonne Ag and 0.69 g/tonne Au.													
6) CANAL LAKE AREA													
58°22' 69°59' 24K/5 6144 Tp. 438 km NNW of Schefferville, Quebec.	66RF 0837	Galena	II	1.433 1.443	22.57 22.62	22.87 22.87	53.13 53.07	15.78 15.72	15.99 15.89	37.15 36.88	1.013 1.011	2.354 2.346	
Pyrrhotite with chalcopyrite in gabbro.													

GEOLOGICAL SURVEY OF CANADA COMMISSION GÉOLOGIQUE DU CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES

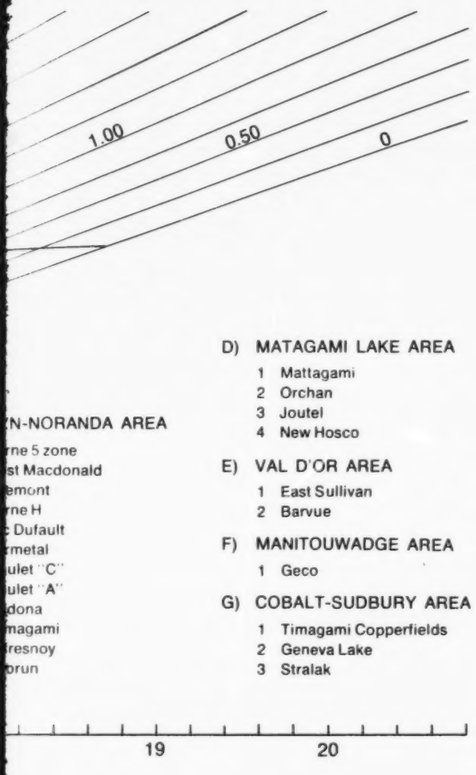


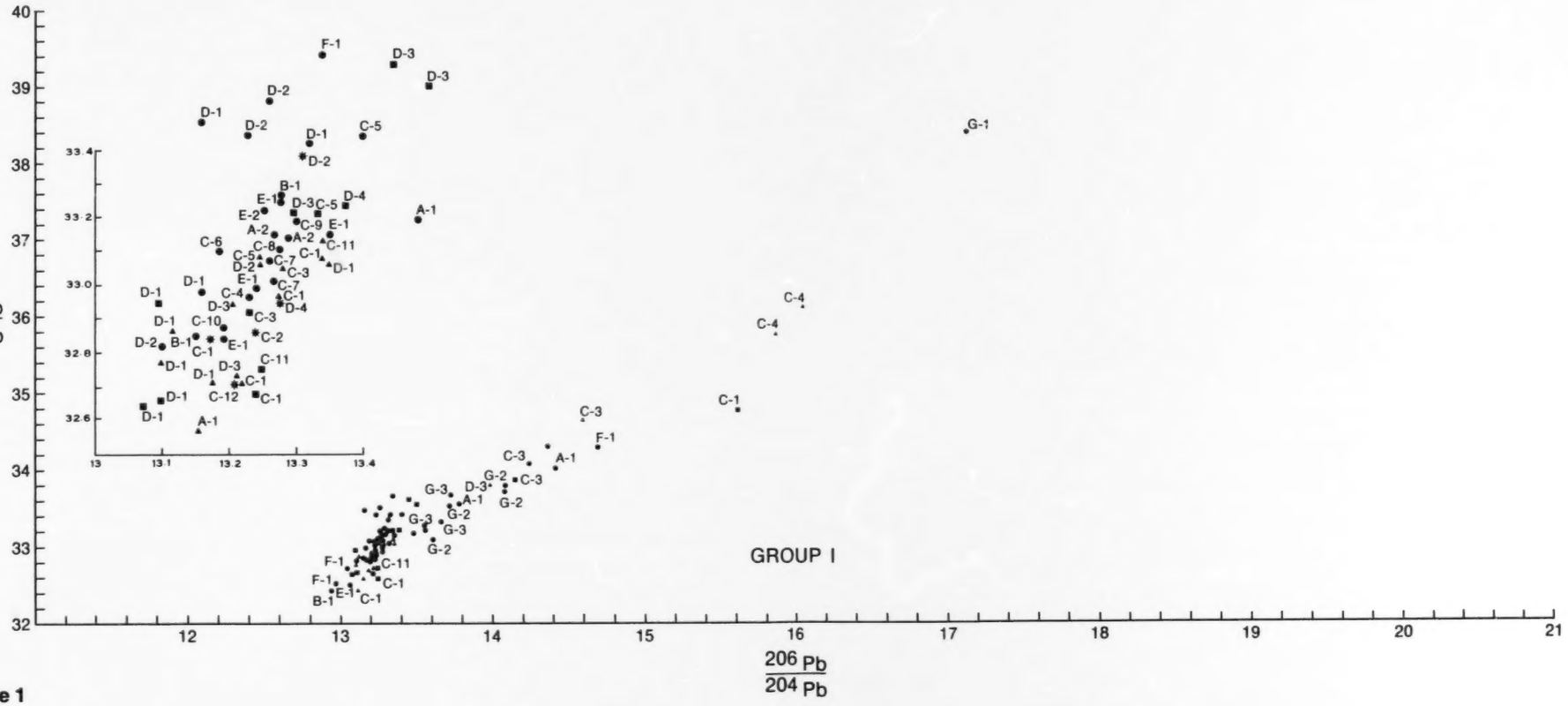


Appendix Figure 1

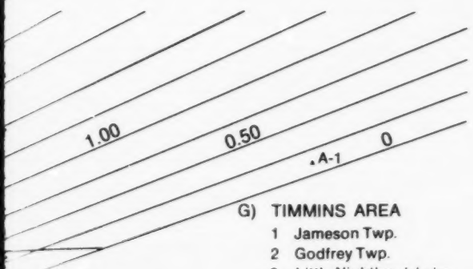
GEOLOGICAL SURVEY OF CANADA COMMISSION GÉOLOGIQUE DU CANADA

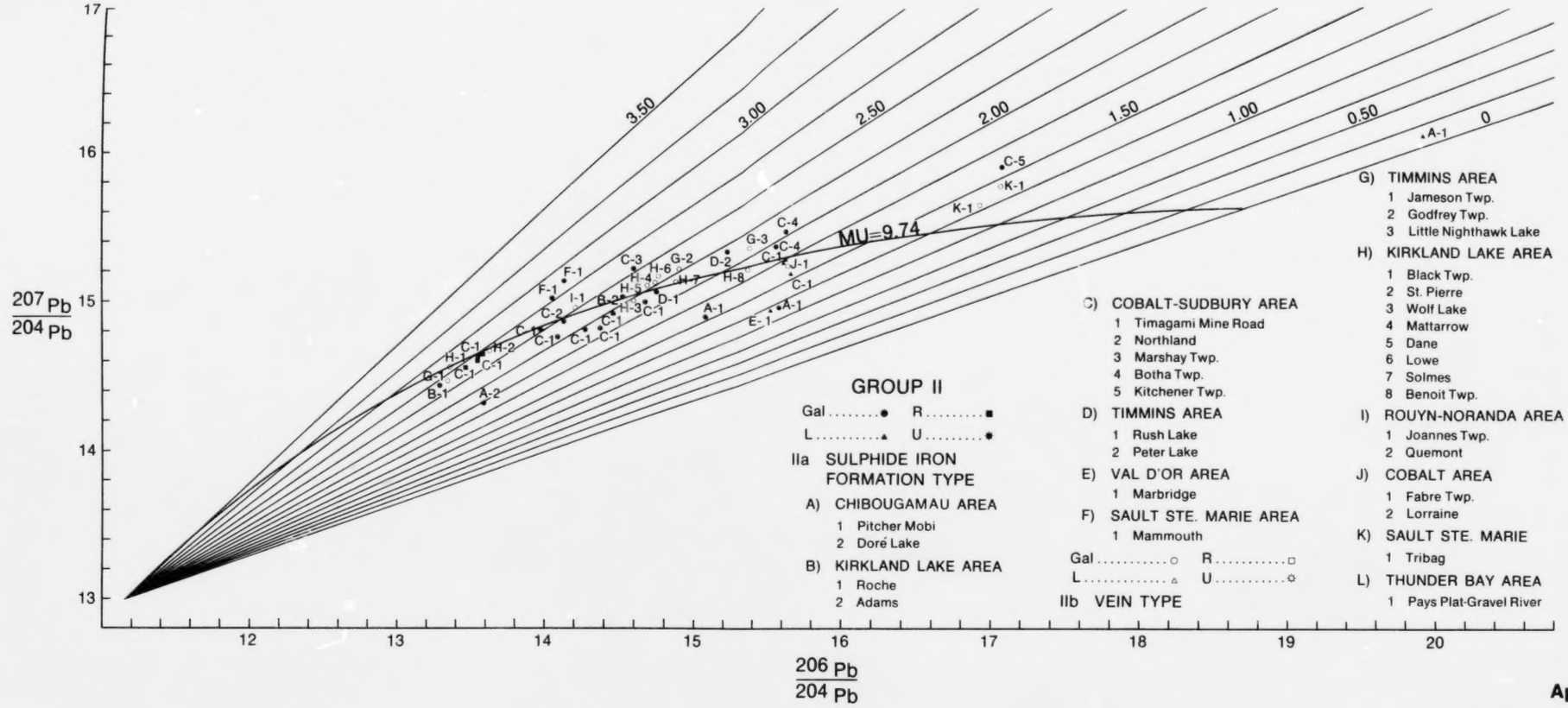
DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES

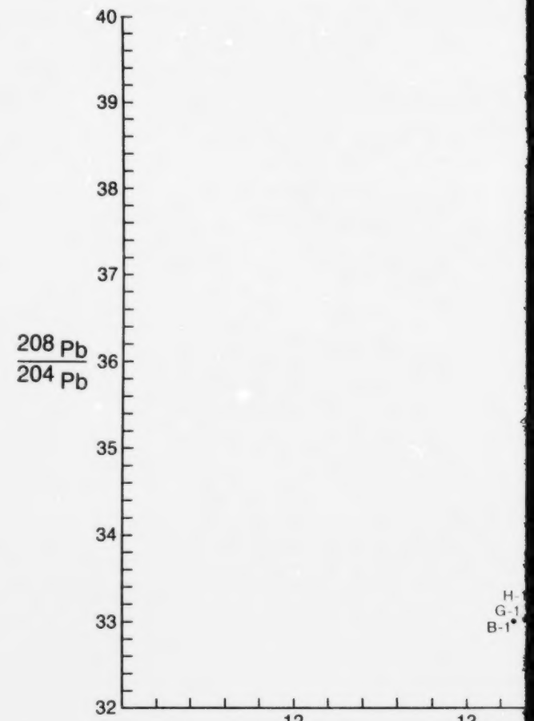


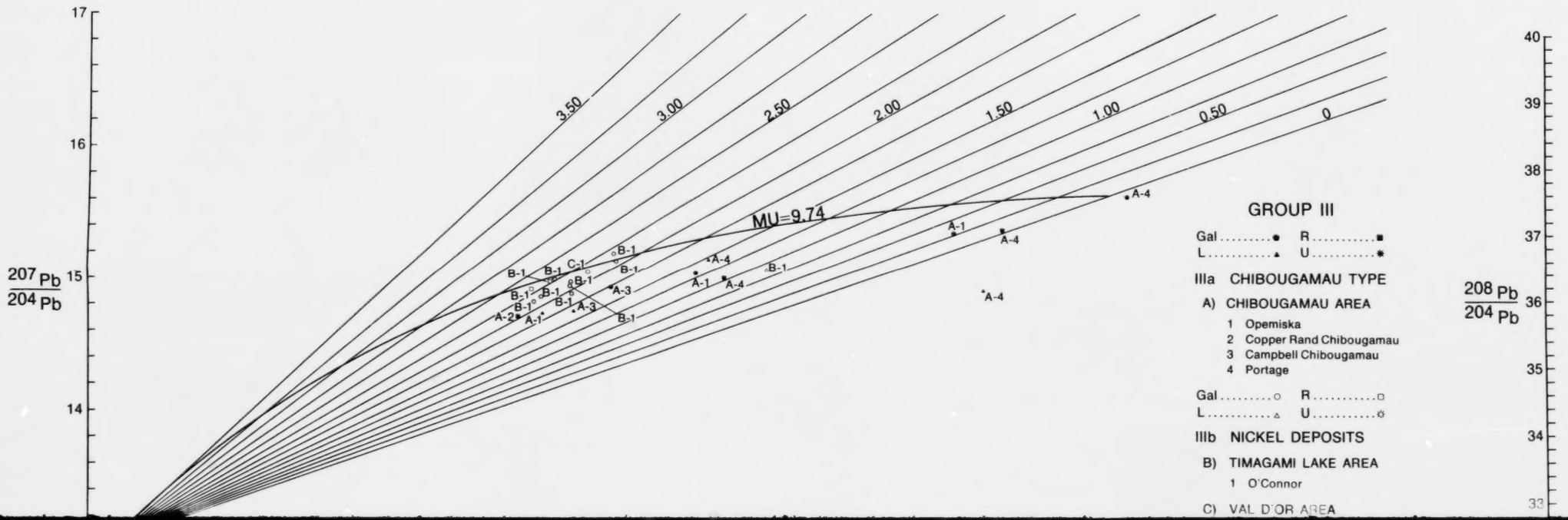


Appendix Figure 1

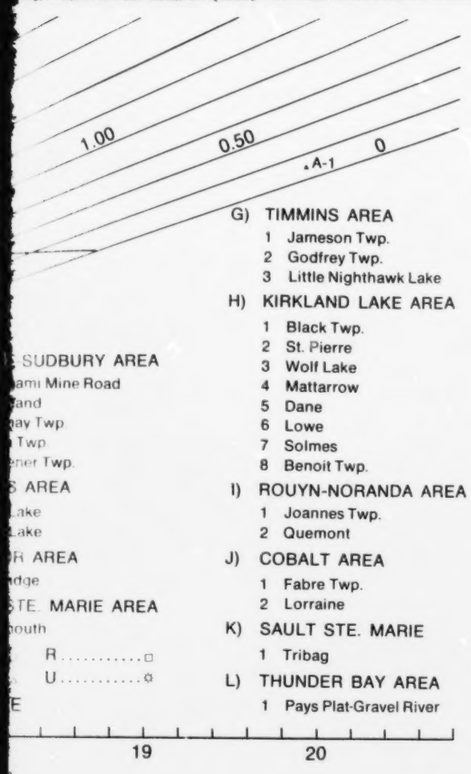


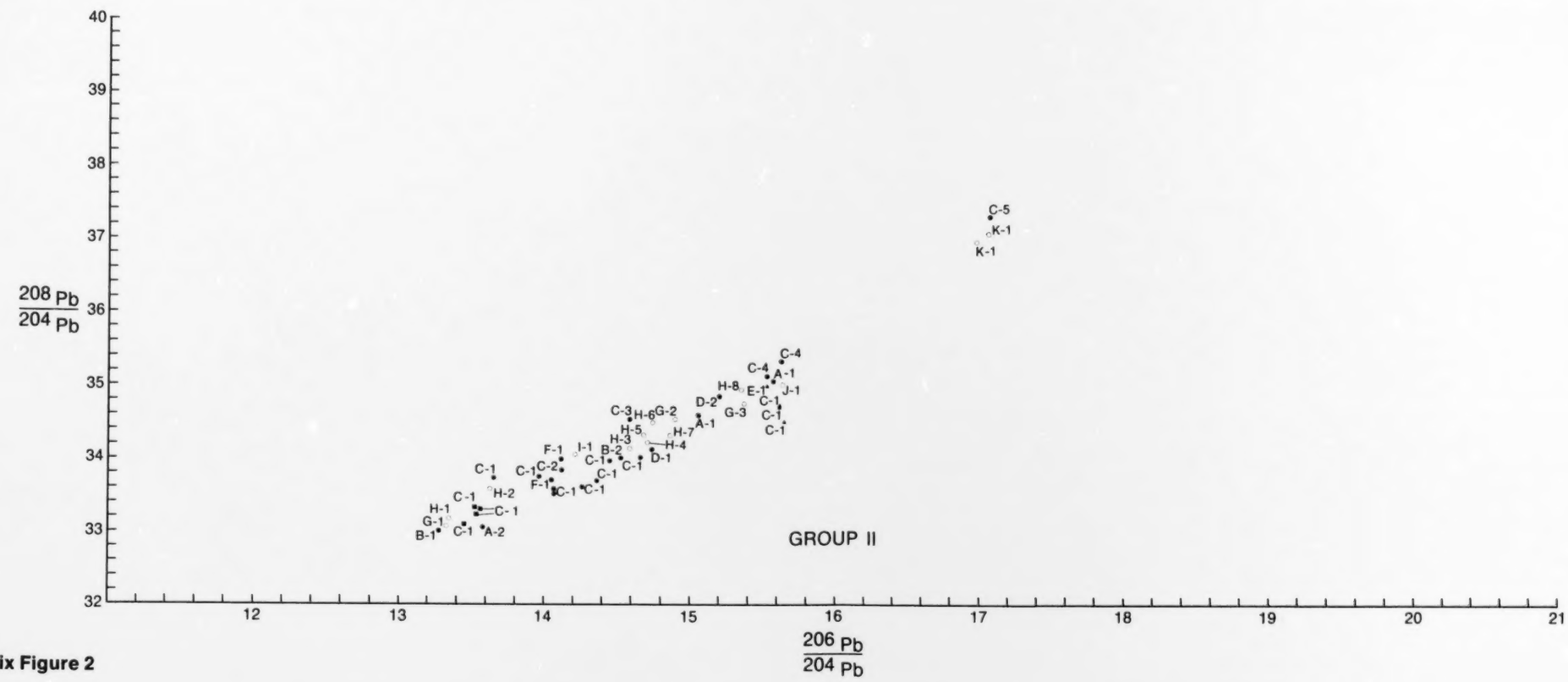




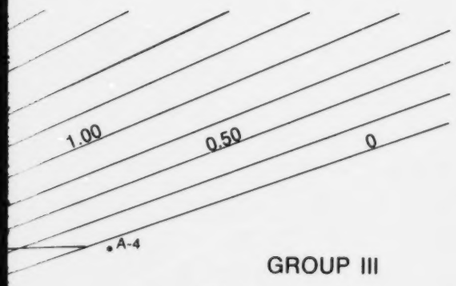


Appendix Figure 2





Appendix Figure 2



GROUP III

Gal ..... R .....
L ..... U .....

IIIa CHIBOUGAMAU TYPE

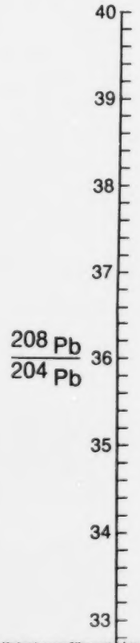
A) CHIBOUGAMAU AREA
1 Opemiska
2 Copper Rand Chibougamau
3 Campbell Chibougamau
4 Portage

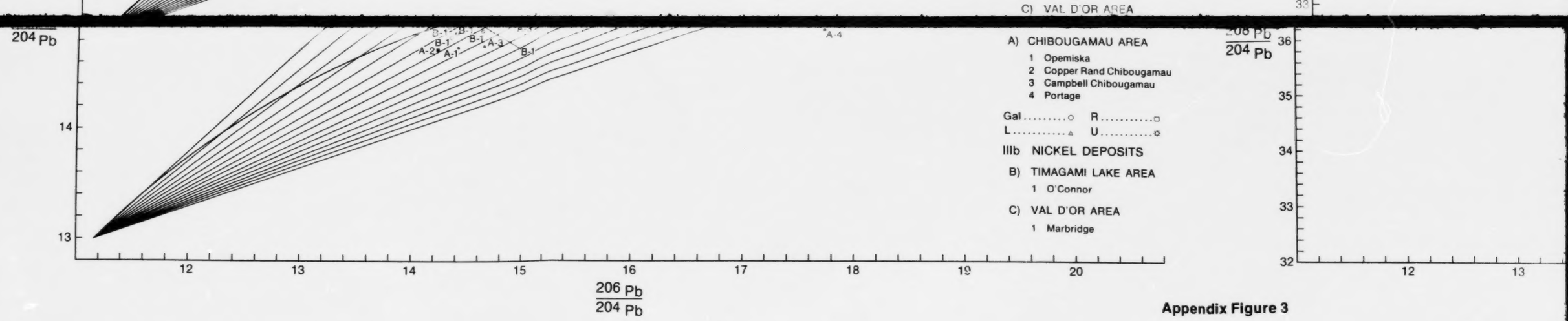
Gal ..... R .....
L ..... U .....

IIIb NICKEL DEPOSITS

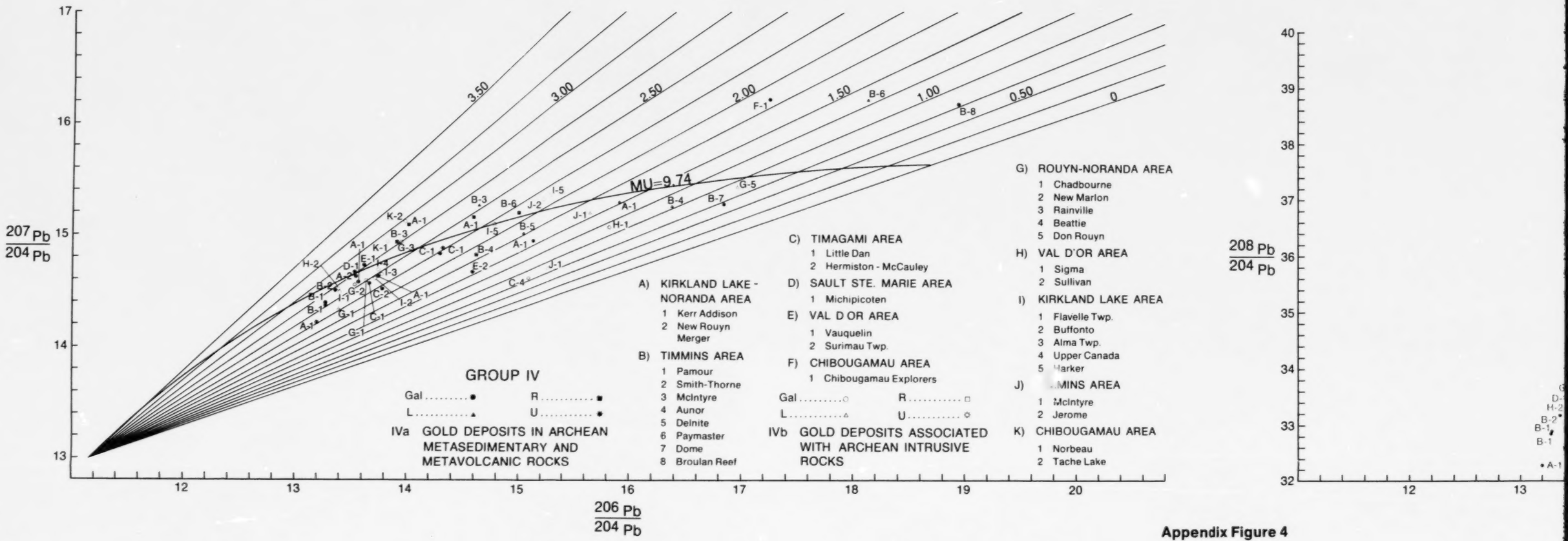
B) TIMAGAMI LAKE AREA
1 O'Connor

C) VAL D'OR AREA





Appendix Figure 3



Appendix Figure 4

C) VAL D'OR AREA

A) CHIBOUGAMAU AREA
1 Opemiska
2 Copper Rand Chibougamau
3 Campbell Chibougamau
4 Portage

Gal ..... ○ R ..... □
L ..... △ U ..... ☼

IIIb NICKEL DEPOSITS

B) TIMAGAMI LAKE AREA
1 O'Connor

C) VAL D'OR AREA
1 Marbridge

GROUP III

$\frac{207\ Pb}{204\ Pb}$

$\frac{206\ Pb}{204\ Pb}$

Appendix Figure 3

1.00 0.50 0

B-8

G) ROUYN-NORANDA AREA
1 Chadbourne
2 New Marlon
3 Rainville
4 Beattie
5 Don Rouyn

H) VAL D'OR AREA
1 Sigma
2 Sullivan

I) KIRKLAND LAKE AREA
1 Flavelle Twp
2 Buffonto
3 Alma Twp.
4 Upper Canada
5 Harker

J) TIMMINS AREA
1 McIntyre
2 Jerome

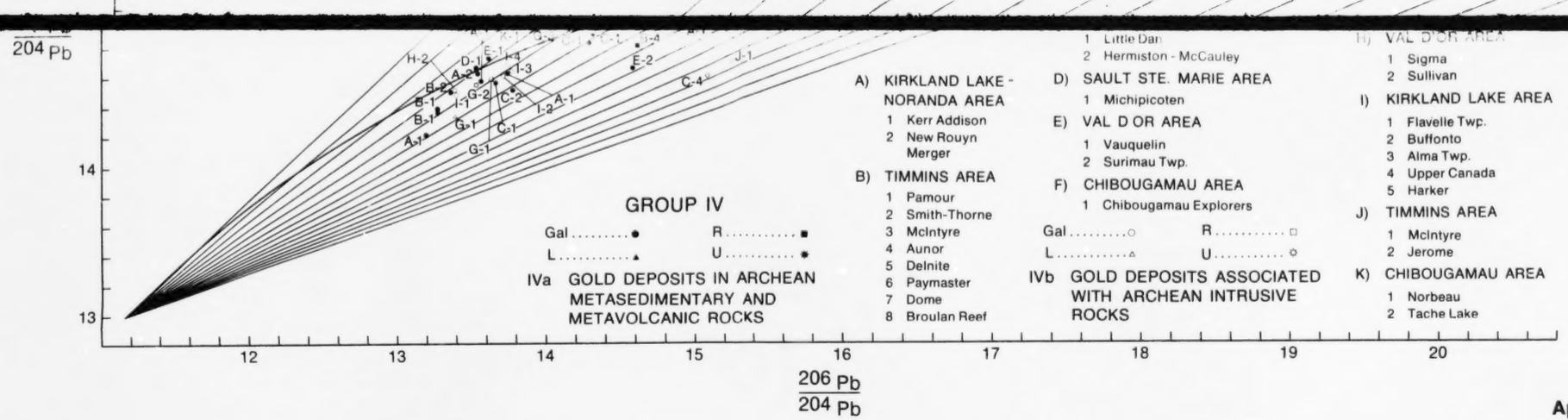
K) CHIBOUGAMAU AREA
1 Norbeau
2 Tache Lake

GROUP IV

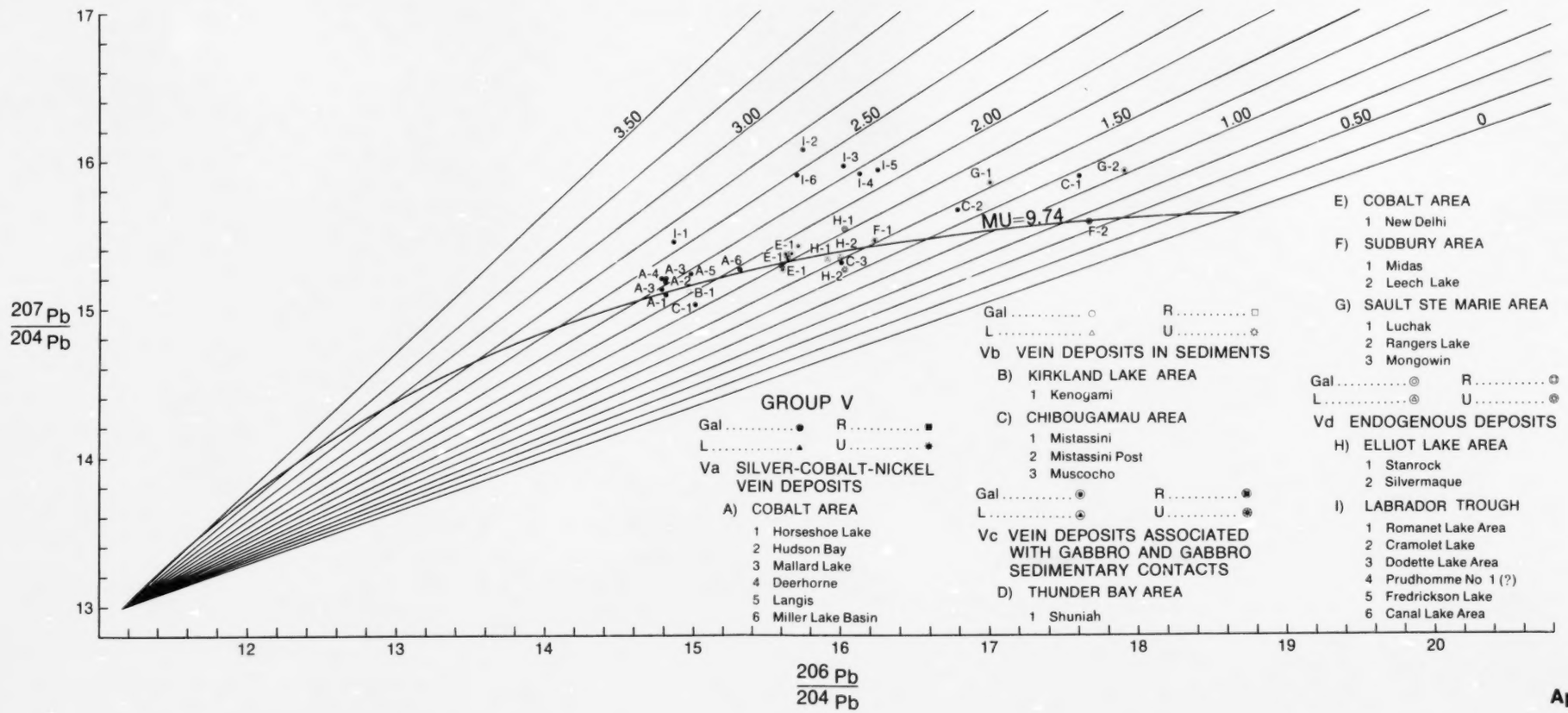
$\frac{208\ Pb}{204\ Pb}$

$\frac{206\ Pb}{204\ Pb}$

Appendix Figure 4



Appendix Figure 4



Appendix Figure 5

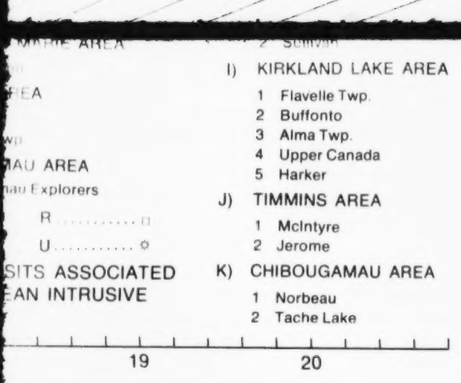
Canada

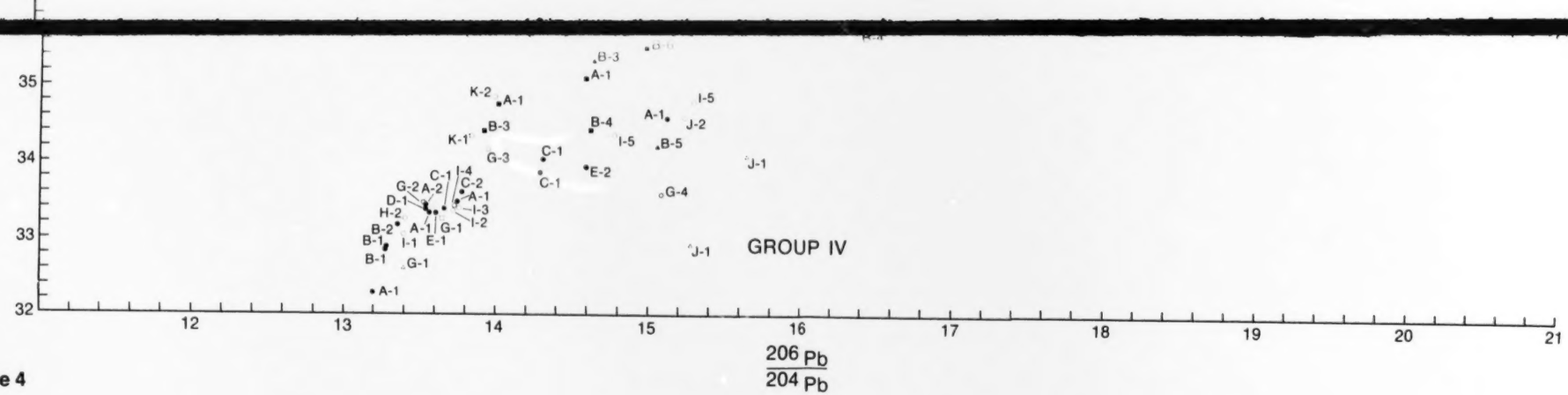
...AU AREA
...au Explorers
R ..... □
U ..... ☼
SITS ASSOCIATED
AN INTRUSIVE

I) KIRKLAND LAKE AREA
1 Flavelle Twp.
2 Buffonto
3 Alma Twp.
4 Upper Canada
5 Harker

J) TIMMINS AREA
1 McIntyre
2 Jerome

K) CHIBOUGAMAU AREA
1 Norbeau
2 Tache Lake





Appendix Figure 4

1.00
0.50
0

E) COBALT AREA
1 New Delhi

F) SUDBURY AREA
1 Midas
2 Leech Lake

G) SAULT STE MARIE AREA
1 Luchak
2 Rangers Lake
3 Mongowin

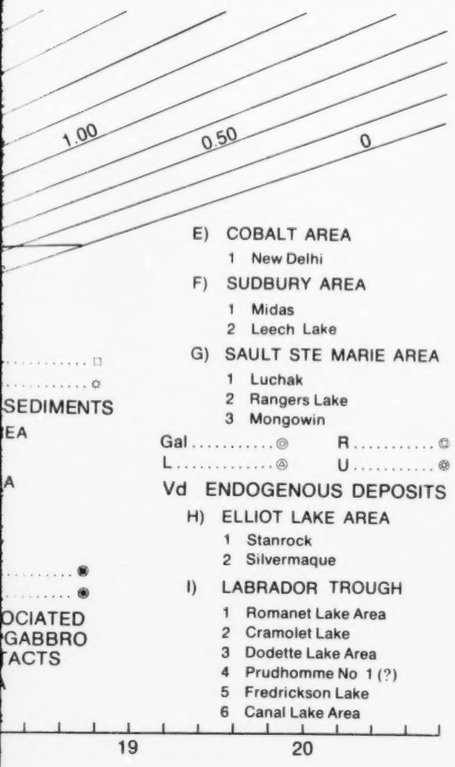
..... □
..... ☼
SEDIMENTS
EA
A
..... ◉
..... ◉
OCIATED
GABBRO
TACTS

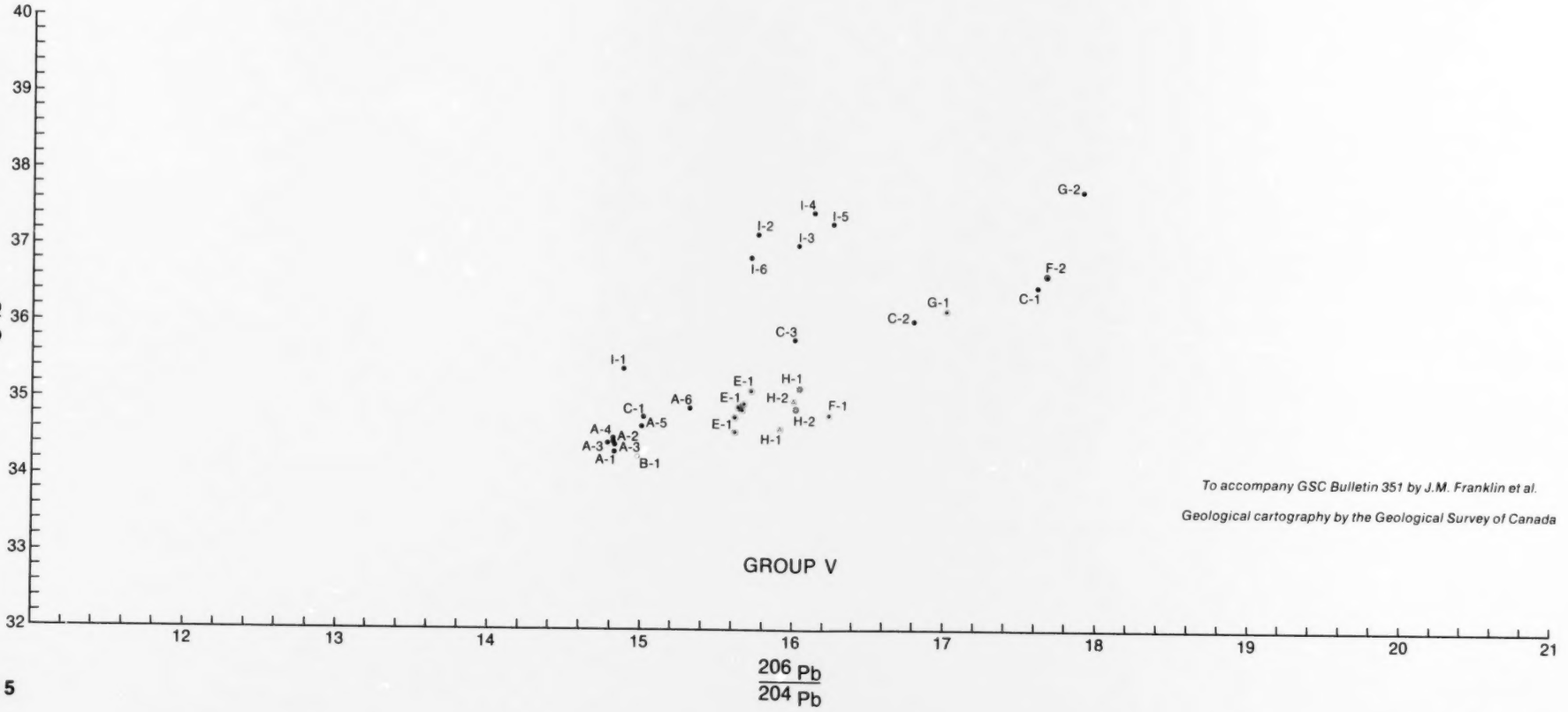
Gal ..... ◎ R ..... ©
L ..... ◎ U ..... ❁

Vd ENDOGENOUS DEPOSITS

H) ELLIOT LAKE AREA
1 Stanrock
2 Silvermaque

I) LABRADOR TROUGH
1 Romanet Lake Area
2 Cramolet Lake
3 Dodette Lake Area
4 Prudhomme No 1 (?)
5 Fredrickson Lake
6 Canal Lake Area





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Geological cartography by the Geological Survey of Canada

Appendix Figure 5

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